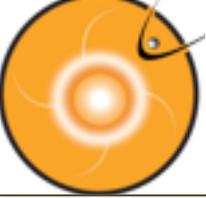


Outline

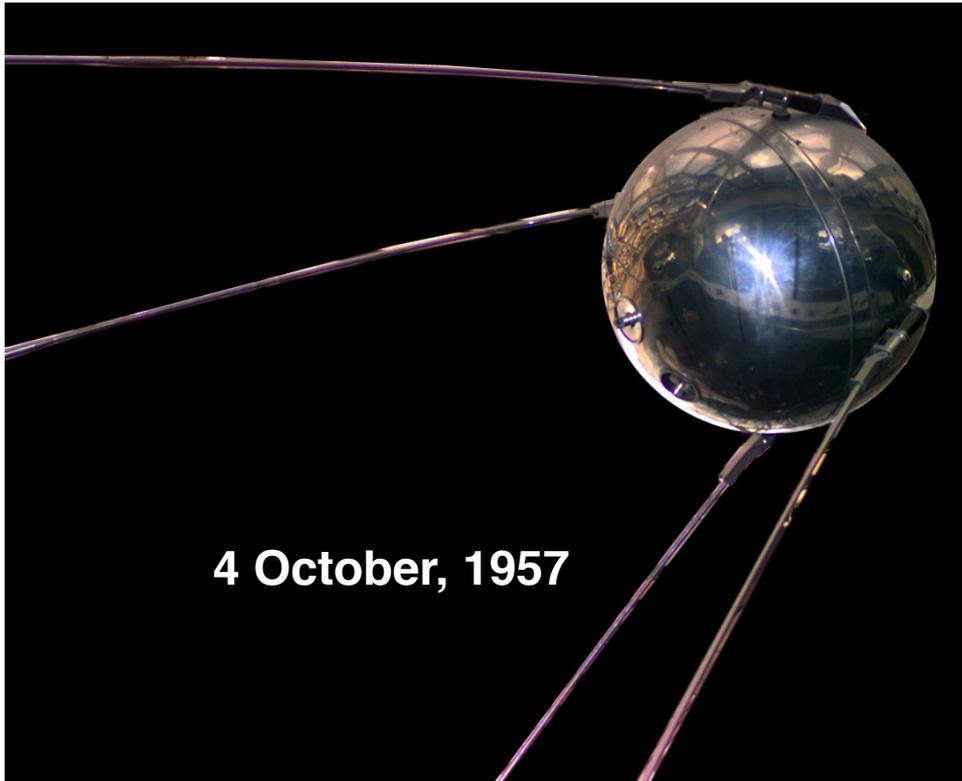
- ✓ Intro of man-made satellites
- ✓ Orbits
- ✓ Different types of space weather effects on satellites
- ✓ Satellite anomalies from the Oct 2003 and the March 2012 SWx events

Acknowledge:
Mike Xapsos
Joe Minow

Yihua Zheng
June 8, 2017



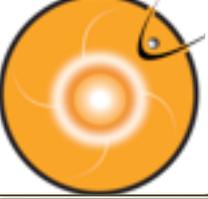
1st Satellite Launched Into Space



The world's first artificial satellite, the **Sputnik 1**, was launched by the Soviet Union in 1957.

marking the start of the Space Age

International Geophysical Year: 1957



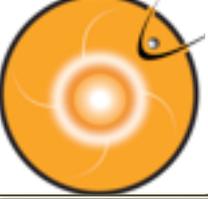
Space dog - Laika



the occupant of the Soviet spacecraft Sputnik 2 that was launched into outer space on **November 3, 1957**



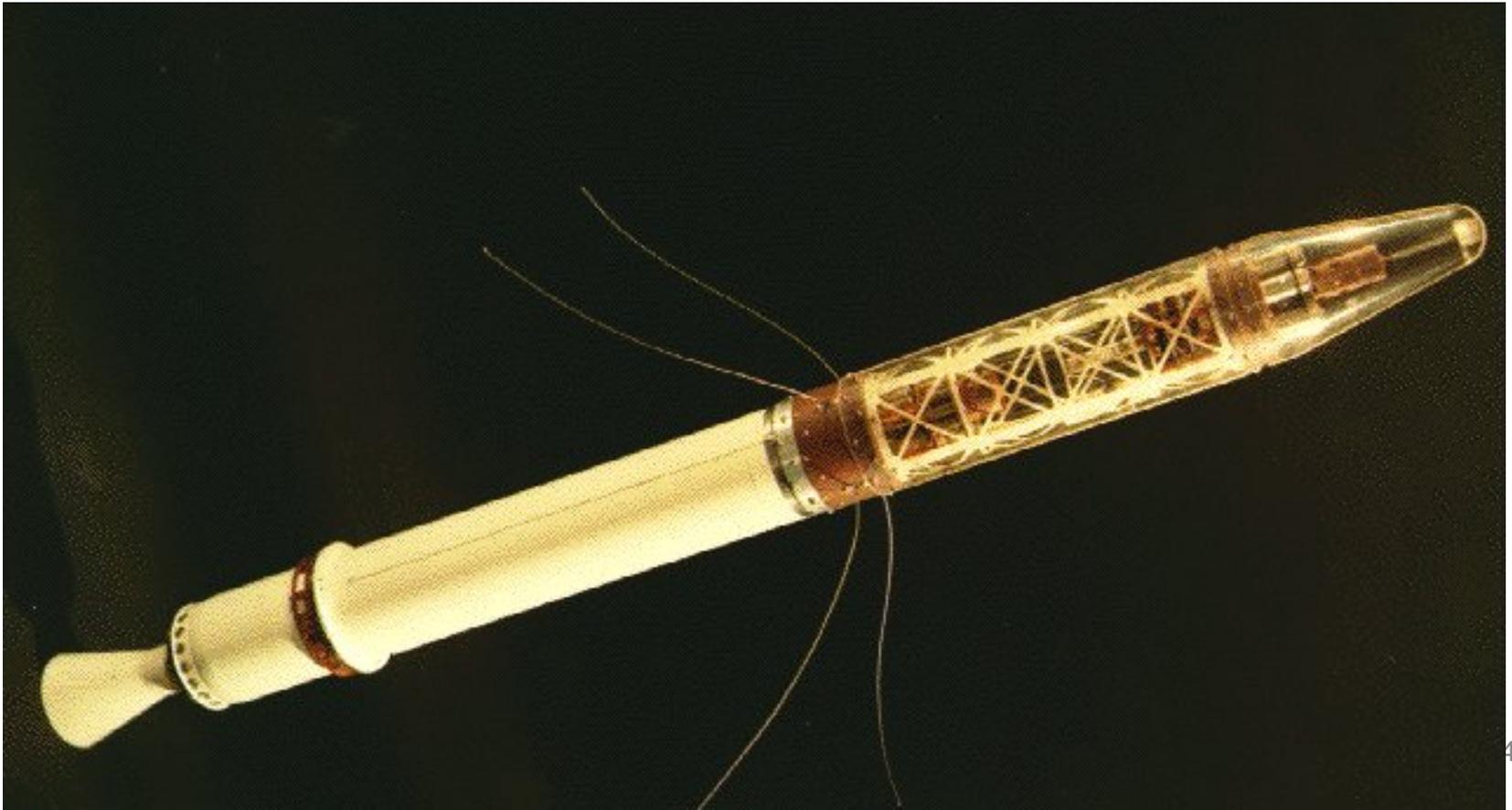
Paving the way for human missions

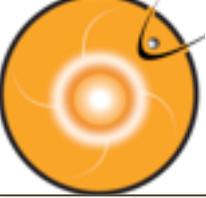


Explorer I – 1st U.S. Satellite



- Explorer 1, was launched into Earth's orbit on a Jupiter C missile from Cape Canaveral, Florida, on January 31, 1958



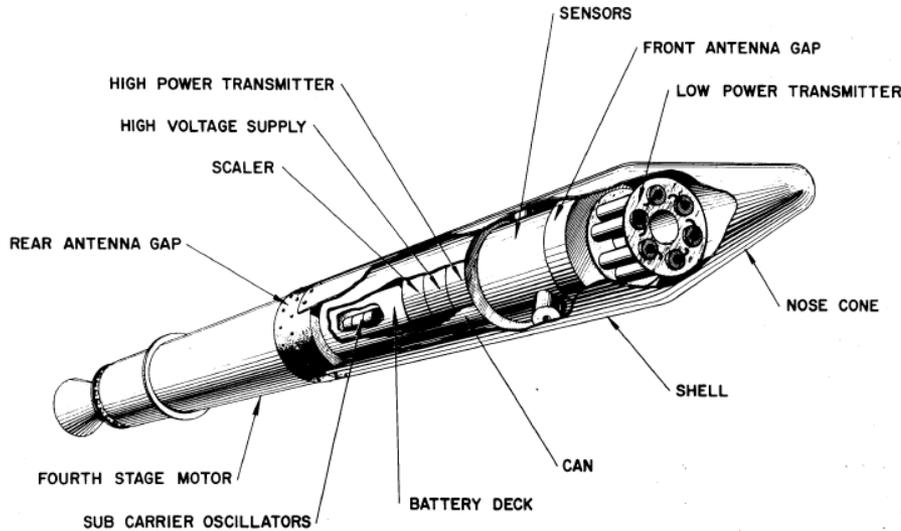


Discovery of the Outer Van Allen RB



NASA National Aeronautics and Space Administration

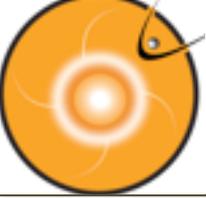
Headquarters Washington, D.C.



EXPLORER IV

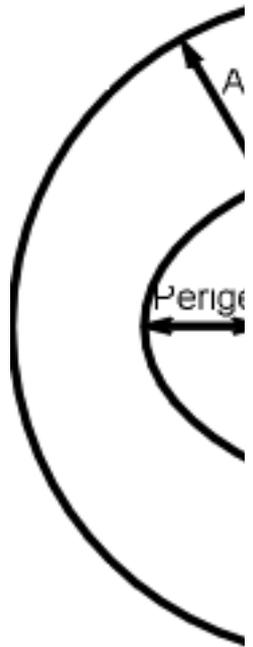


Pioneer 3 (launched 6 December 1958) and **Explorer IV** (launched July 26, 1958) both carried instruments designed and built by Dr. Van Allen. These spacecraft provided Van Allen additional data that led to discovery of **a second radiation belt**

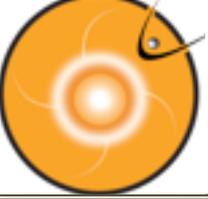


Orbits

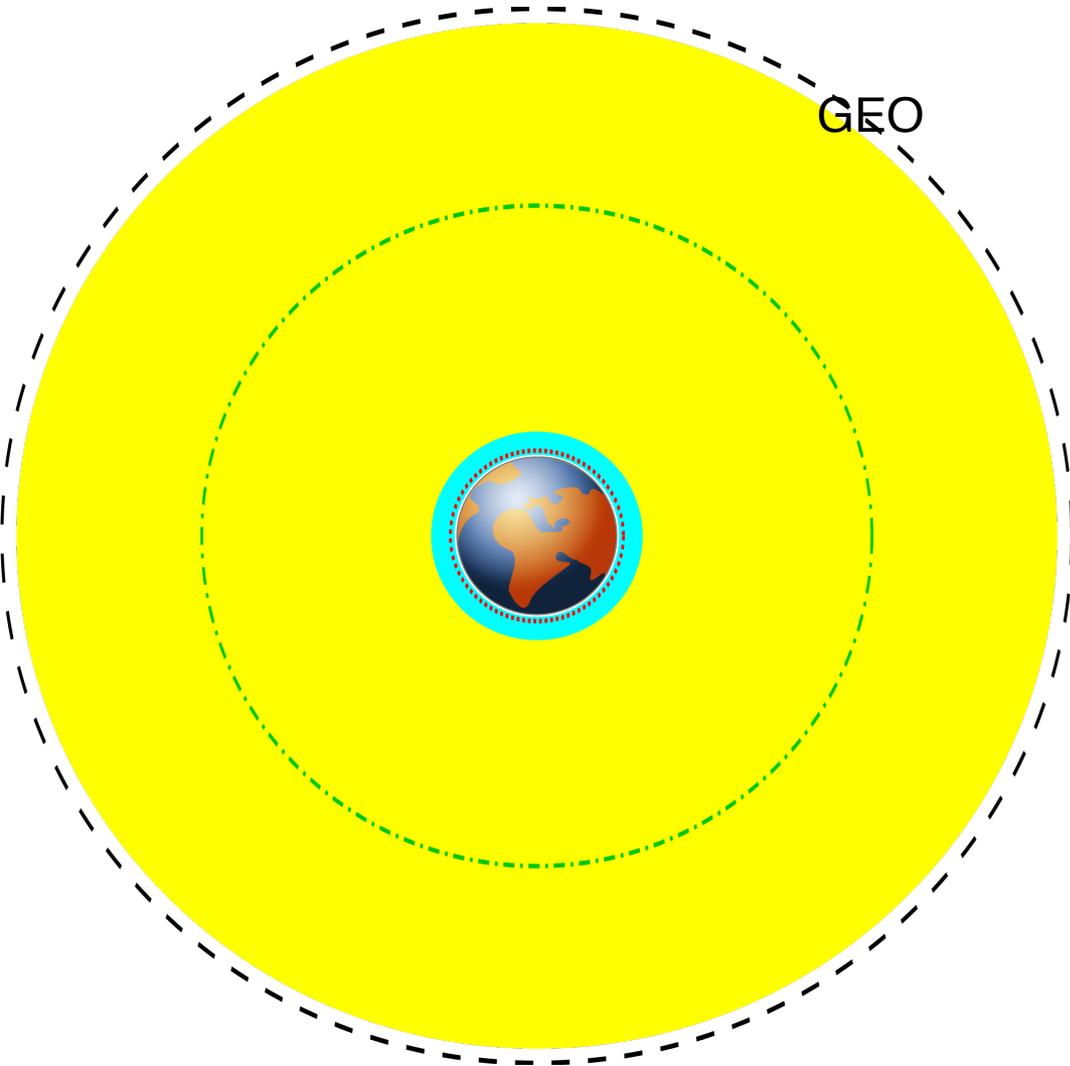
| ORBIT NAME | ORBIT INITIALS | ORBIT ALTITUDE (KM ABOVE EARTH'S SURFACE) | DETAILS / COMMENTS |
|----------------------|----------------|---|---|
| Low Earth Orbit | LEO | 200 – 1200 | |
| Medium Earth Orbit | MEO | 1200 – 35790 | |
| Geosynchronous Orbit | GSO | 35790 | Orbits once a day, but not necessarily in the same direction as the rotation of the Earth – not necessarily stationary |
| Geostationary Orbit | GEO | 35790 | Orbits once a day and moves in the same direction as the Earth and therefore appears stationary above the same point on the Earth's surface. Can only be above the Equator. |
| High Earth Orbit | HEO | Above 35790 | |



G



Orbits



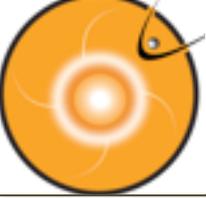
GEO

Yellow: MEO

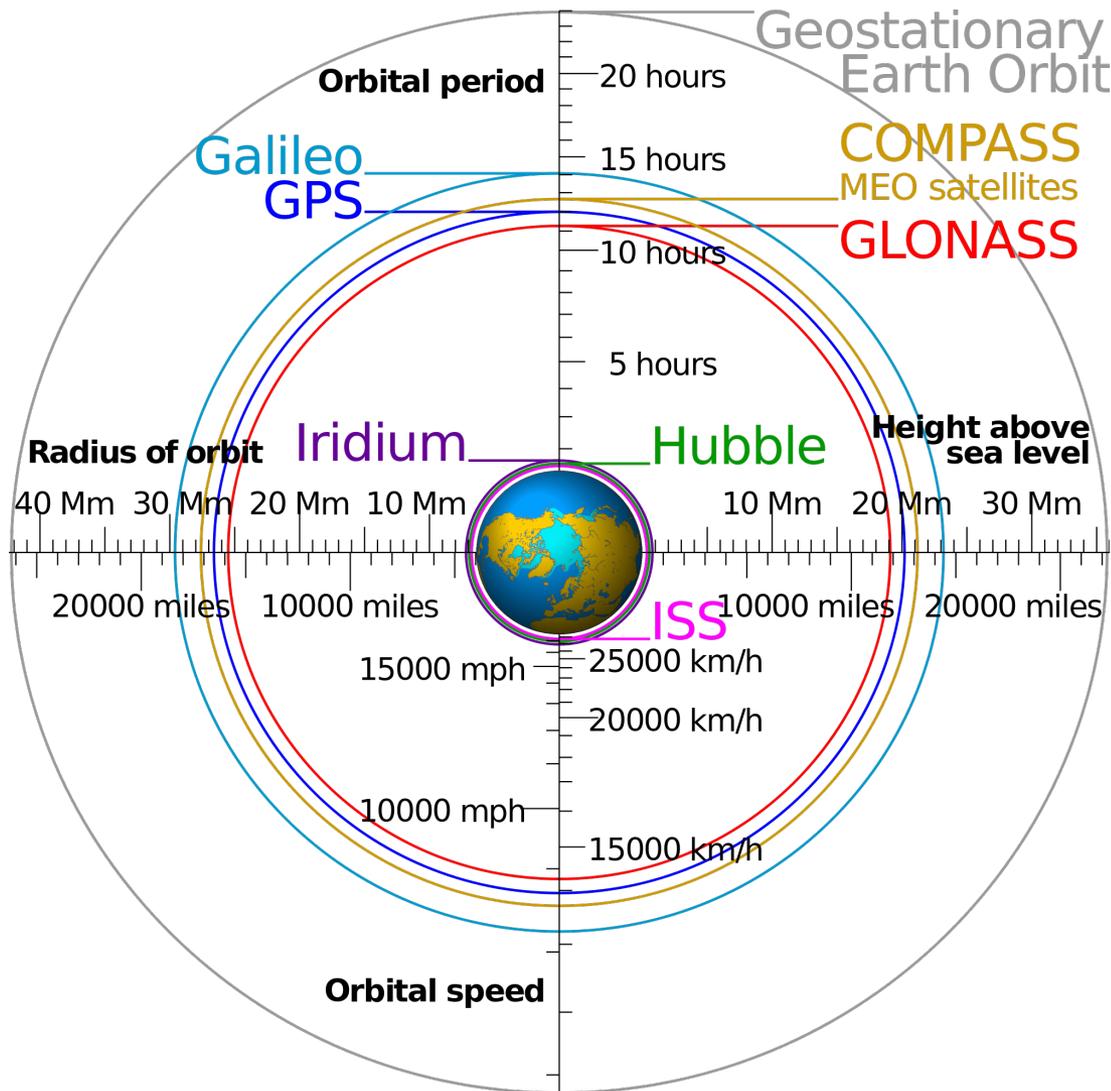
Green-dash-dotted line: GPS

Cyan: LEO

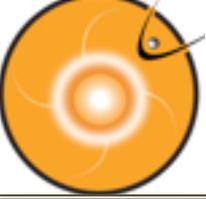
Red dotted line: ISS



Orbits



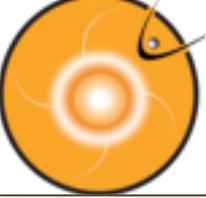
Different observing assets in near-Earth environment



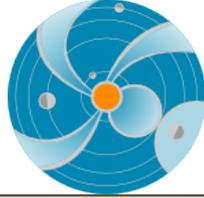
Orbits



- A **low Earth orbit (LEO)** is generally defined as an orbit below an altitude of 2,000 km. Given the rapid orbital decay of objects below approximately 200 km, the commonly accepted definition for LEO is between 160–2,000 km (100–1,240 miles) above the Earth's surface.
- **Medium Earth orbit (MEO)**, sometimes called **intermediate circular orbit (ICO)**, is the region of space around the Earth above low Earth orbit (altitude of 2,000 kilometres (1,243 mi)) and below geostationary orbit (altitude of 35,786 km (22,236 mi)).

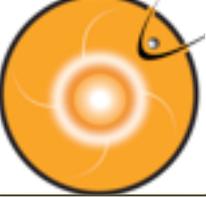


Orbit classification based on inclination

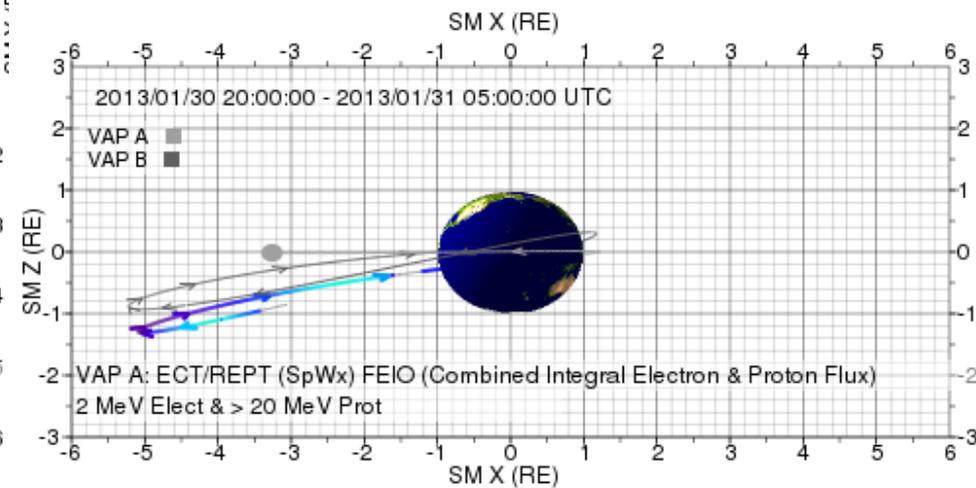
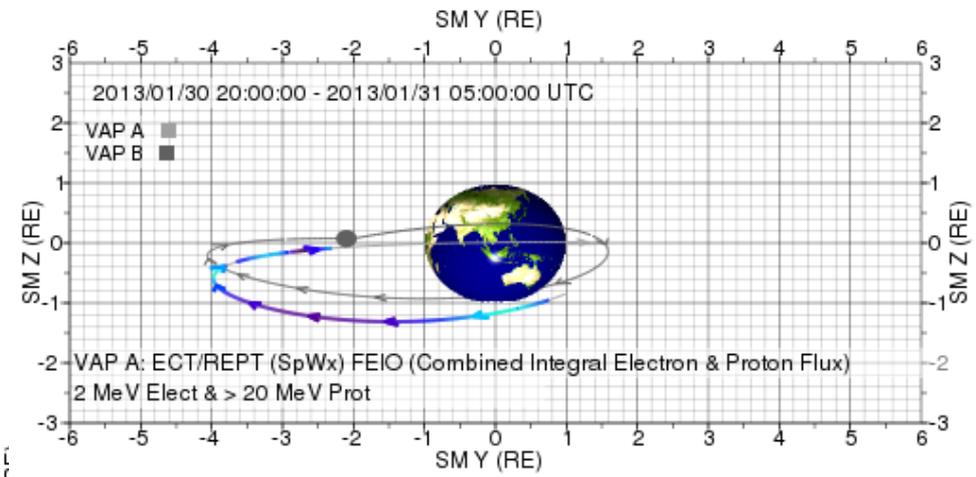
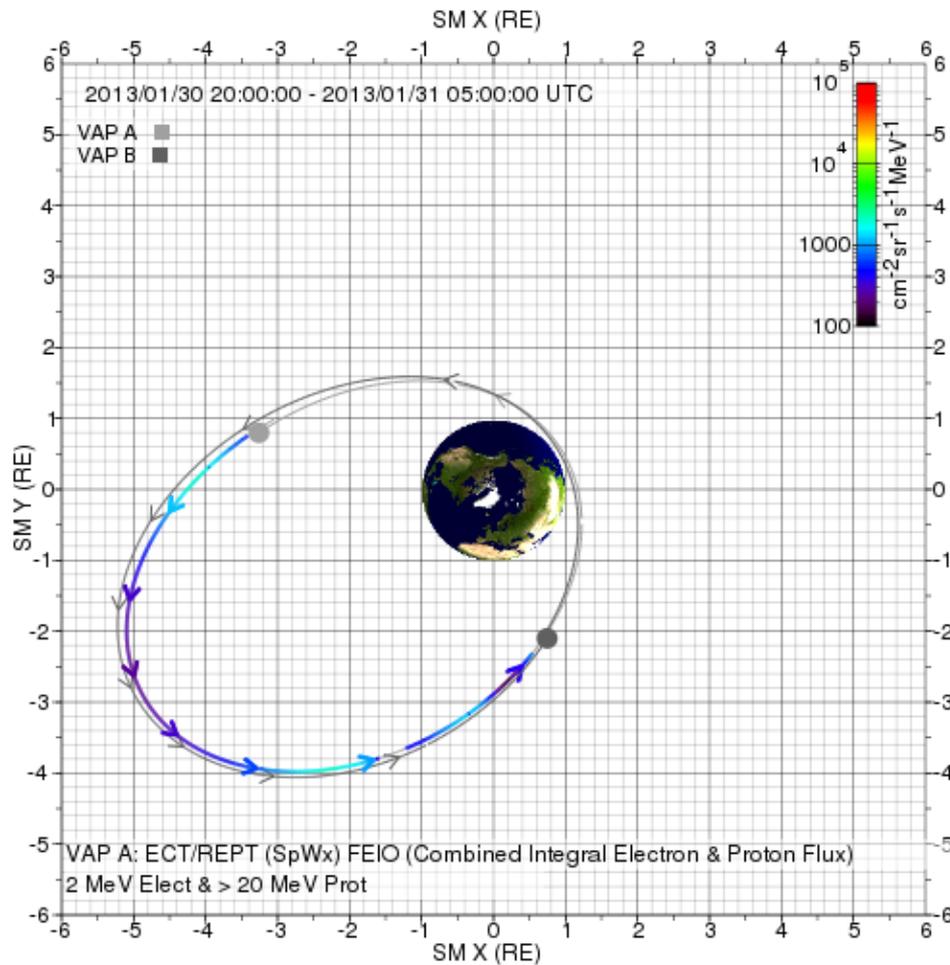


- **Inclined orbit:** An orbit whose inclination in reference to the [equatorial plane](#) is not zero degrees.
 - **Polar orbit:** An orbit that passes above or nearly above both poles of the planet on each revolution. Therefore it has an inclination of (or very close to) 90 [degrees](#).
 - **Polar sun synchronous orbit:** A nearly polar orbit that passes the equator at the same local time on every pass. Useful for image taking satellites because shadows will be nearly the same on every pass.

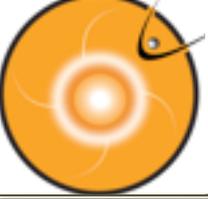
DMSP satellites



Van Allen Probes



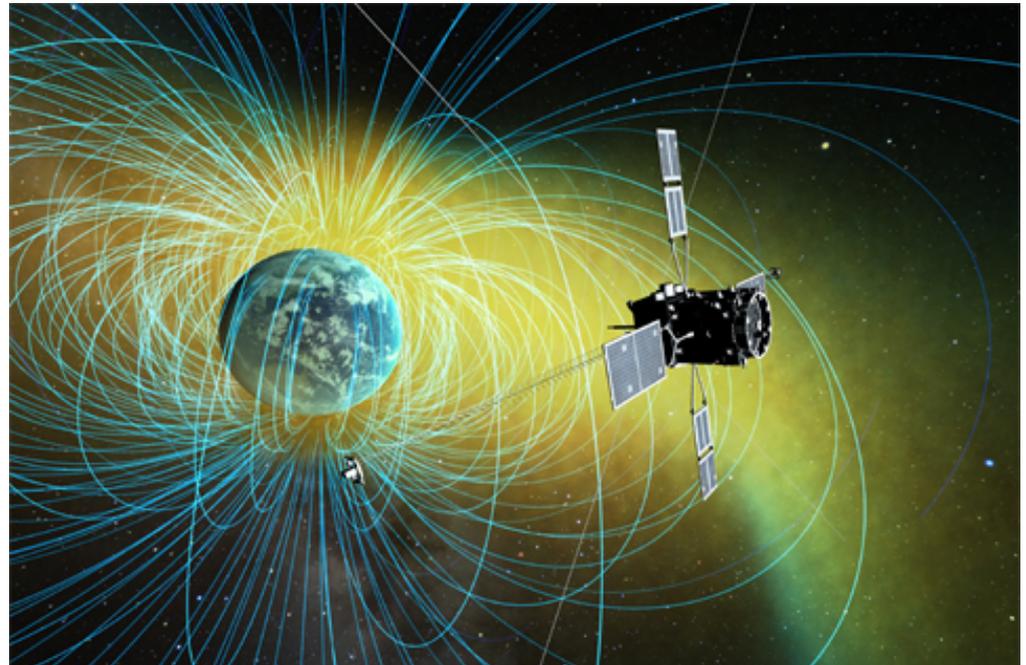
Two Spacecraft In an Elliptical Orbit

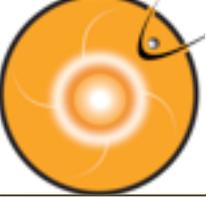


ERG/Arase

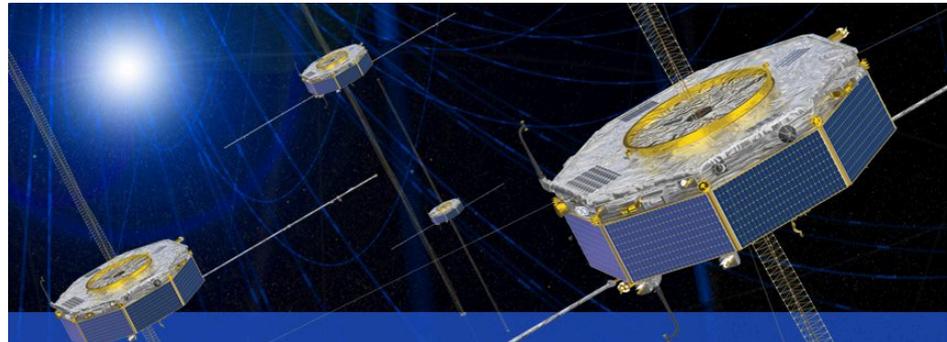
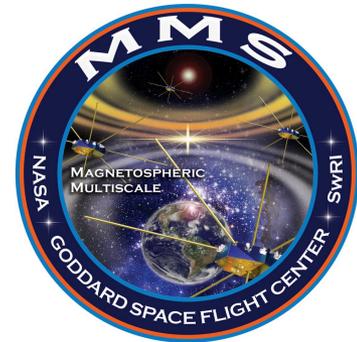
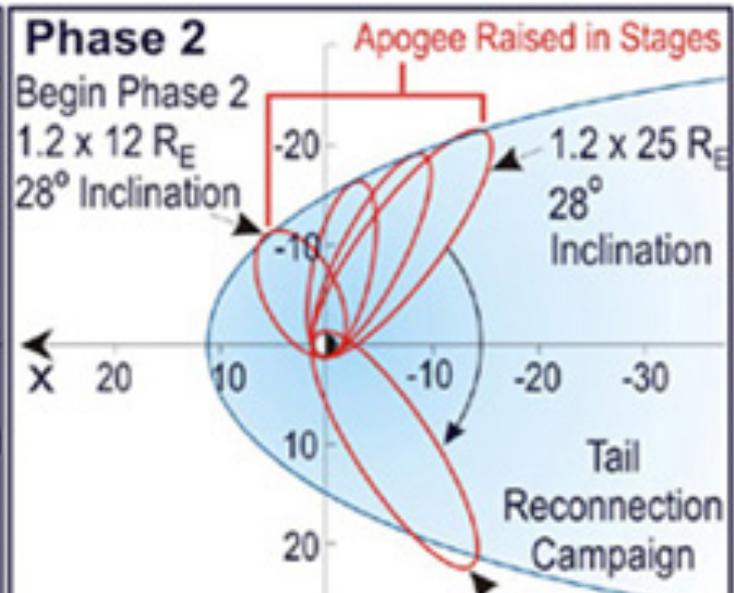
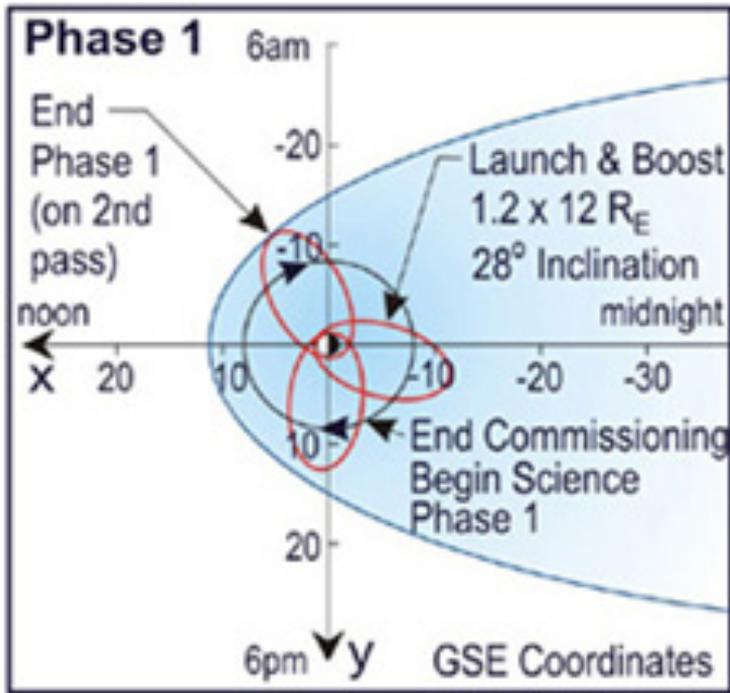
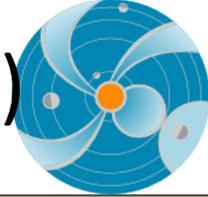


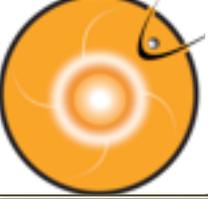
- Orbit info
 - Altitude
 - Perigee about 440 km, Apogee: about 32,000 km
 - Inclination
 - 32 degrees
 - Elliptical orbit
 - Period: 570 min





MMS (Magnetospheric Multiscale Mission)





Other types of orbits

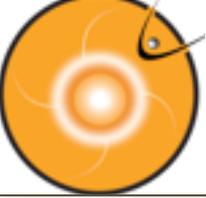


Heliocentric orbit: An orbit around the Sun.

STEREO A and STEREO B

Interplanetary space

At different planets



Orbit/Mission Design



- [New Horizon to Pluto](#)

**Closest approach to Pluto: 7:49:57 a.m. EDT
(11:49:57 UTC) on July 14, 2015**

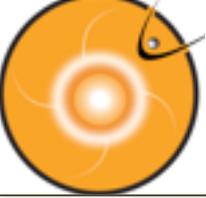
<http://www.jhu.edu/jhumag/1105web/pluto.html>

Dr. Yanping Guo, a mission design specialist at APL

Reduce the journey by three years

For more information about New Horizon

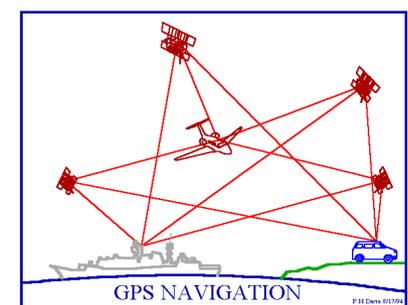
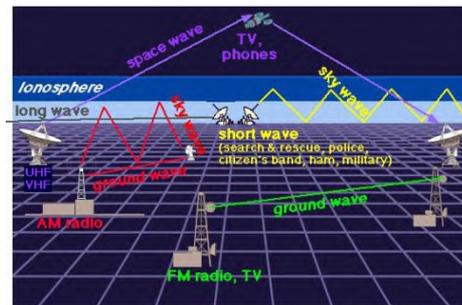
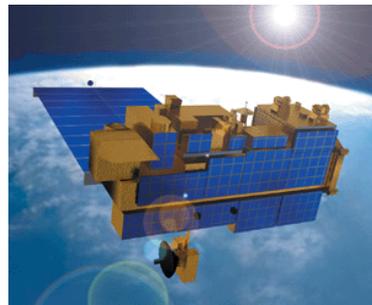
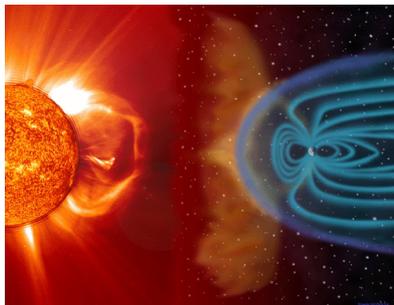
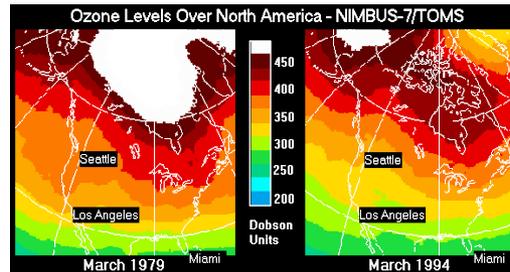
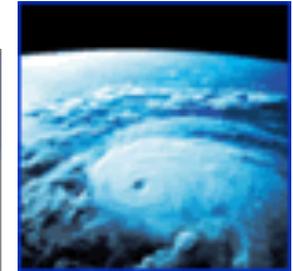
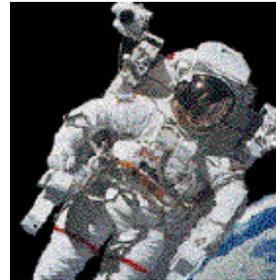
http://www.nasa.gov/mission_pages/newhorizons/main/index.html

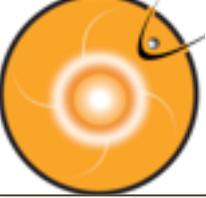


Importance & Our Increasing Reliance on Space Systems



- Scientific Research
 - Space science
 - Earth science
 - Human exploration of space
 - Aeronautics and space transportation
- Navigation
- Telecommunications
- Defense
- Space environment monitoring
- Terrestrial weather monitoring





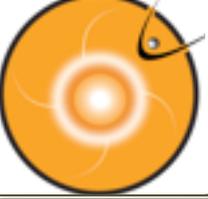
Space Weather and Spacecraft Operations



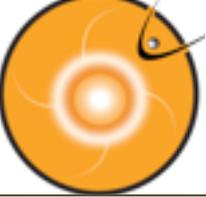
- The primary approach for the spacecraft industry to mitigate the effects of space weather is to **design satellites to operate under extreme environmental conditions to the maximum extent possible within cost and resource constraints**

“Severe Space Weather Events--Understanding Societal and Economic Impacts Workshop Report,”
National Academies Press, Washington, DC, 2008 <http://www.nap.edu/catalog/12507.html>

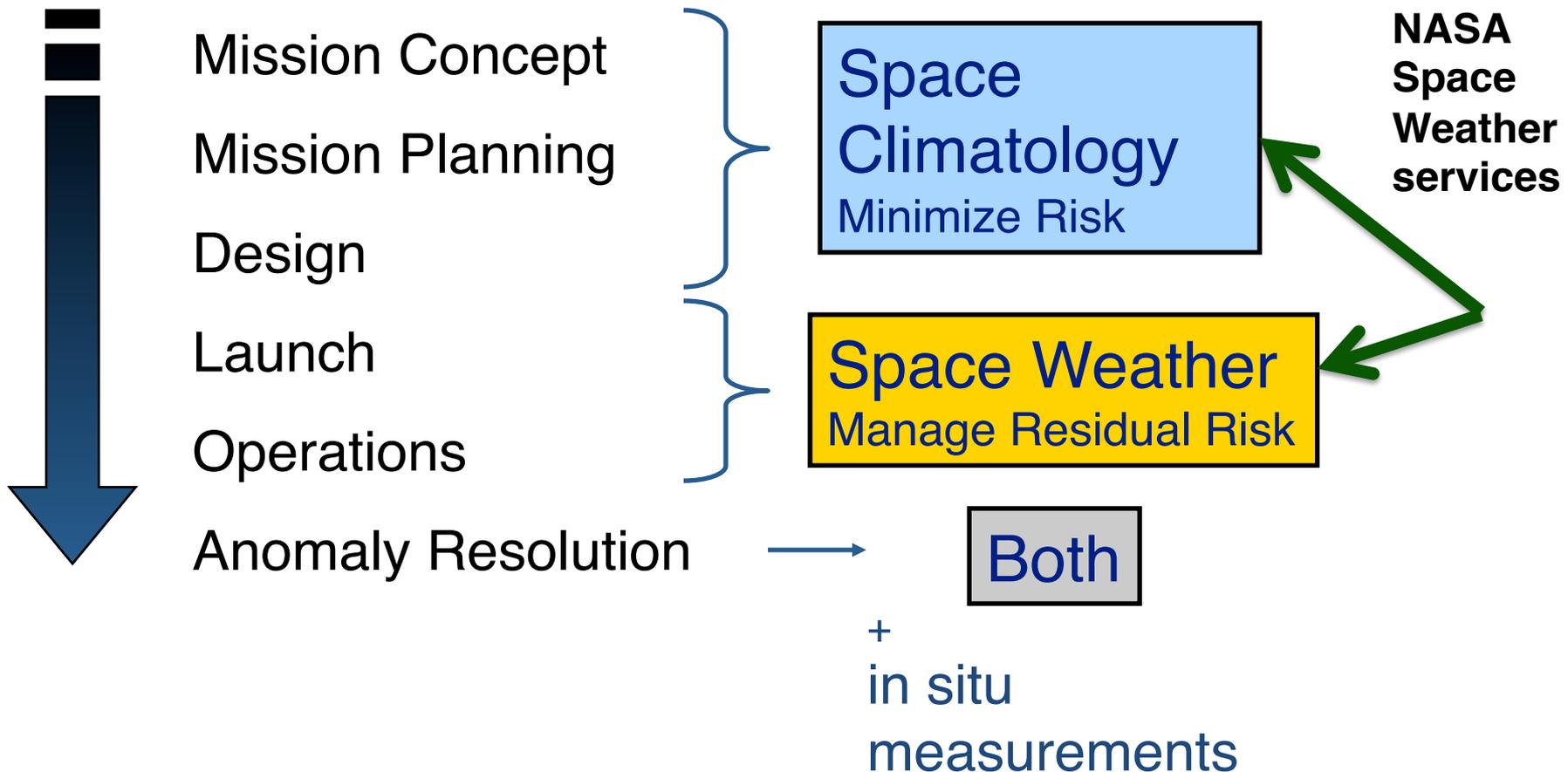
- **This technique is rarely 100% successful and space weather will typically end up impacting some aspect of a space mission**
 - Some space weather issues are common to all spacecraft, e.g., space situational awareness is one example
 - Specific details of space weather interactions with a spacecraft are often unique because spacecraft systems are unique, there is no “standard” space weather support to mission operations

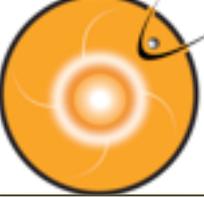


Space Weather impacts on spacecraft operation

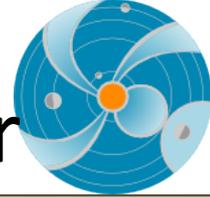


Space Environment Model Use in Mission Life Cycle

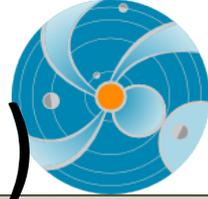
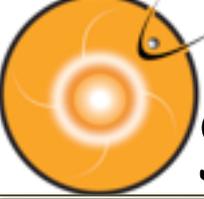




Space Climatology and Space Weather

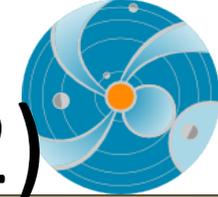
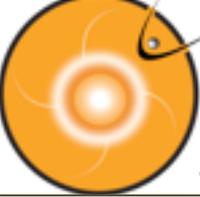


- Space Climatology:
 - Variability over months to years
 - Space environment effects on both satellites and launch vehicles are best mitigated by good design
- Space Weather
 - Variability over minutes to days
 - Effects mitigated by design or operational controls
 - Design satellites to withstand mean, extreme space weather events that may occur during time on orbit



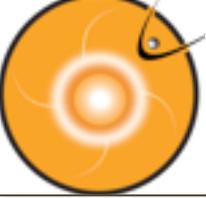
Space Environment & Effects (1)

| Mechanism | Effect | Source |
|---------------------------------------|--|---|
| Total Ionizing Dose (TID) | <ul style="list-style-type: none">• Degradation of microelectronics | <ul style="list-style-type: none">• <i>Trapped protons</i>• <i>Trapped electrons</i>• <i>Solar protons</i> |
| Displacement Damage Dose (DDD) | <ul style="list-style-type: none">• Degradation of optical components and some electronics• Degradation of solar cells | <ul style="list-style-type: none">• <i>Trapped protons</i>• <i>Trapped electrons</i>• <i>Solar protons</i>• <i>Neutrons</i> |
| Single-Event Effects (SEE) | <ul style="list-style-type: none">• Data corruption• Noise on images• System shutdowns• Electronic component damage | <ul style="list-style-type: none">• <i>GCR heavy ions</i>• <i>Solar protons and heavy ions</i>• <i>Trapped protons</i>• <i>Neutrons</i> |
| Surface Erosion | <ul style="list-style-type: none">• Degradation of thermal, electrical, optical properties• Degradation of structural integrity | <ul style="list-style-type: none">• <i>Particle radiation</i>• <i>Ultraviolet</i>• <i>Atomic oxygen</i>• <i>Micrometeoroids</i>• <i>Contamination</i> |



Space Environment & Effects (2)

| Mechanism | Effect | Source |
|---------------------------------|--|--|
| Surface Charging | <ul style="list-style-type: none"> • Biasing of instrument readings • Power drains • Physical damage | <ul style="list-style-type: none"> • <i>Dense, cold plasma</i> • <i>Hot plasma (ring current, aurora population) (few eV to 10s keV)</i> |
| Deep Dielectric Charging | <ul style="list-style-type: none"> • Biasing of instrument readings • Electrical discharges causing • physical damage | <ul style="list-style-type: none"> • <i>High-energy electrons (>300 keV)</i> |
| Structure Impacts | <ul style="list-style-type: none"> • Structural damage • Decompression | <ul style="list-style-type: none"> • <i>Micrometeoroids</i> • <i>Orbital debris</i> |
| Satellite Drag | <ul style="list-style-type: none"> • Torques • Orbital decay | <ul style="list-style-type: none"> • <i>Neutral thermosphere</i> |



Space Environment & Effects



Total Ionizing Dose (TID)

Trapped protons, Trapped electrons, Solar protons

- Degradation of microelectronics

Surface Charging

Dense, cold plasma, Hot plasma

- Biasing of instrument readings
- Power drains
- Physical damage

Displacement Damage Dose (DDD)

Trapped protons, Trapped electrons, Solar protons, Neutrons

- Degradation of optical components and some electronics
- Degradation of solar cells

Deep Dielectric Charging

High-energy electrons

- Biasing of instrument readings
- Electrical discharges causing
- physical damage

Single-Event Effects (SEE)

GCR heavy ions, Solar protons and heavy ions, Trapped protons, Neutrons

- Data corruption
- Noise on images
- System shutdowns
- Electronic component damage

Structure Impacts

Micrometeoroids, Orbital debris

- Structural damage
- Decompression

Surface Erosion

Particle radiation, Ultraviolet, Atomic oxygen, Micrometeoroids, Contamination

- Degradation of thermal, electrical, optical properties
- Degradation of structural integrity

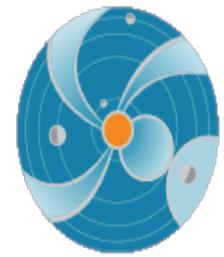
Satellite Drag

Neutral thermosphere

- Torques
- Orbital decay



Space Environment & Effects



Source

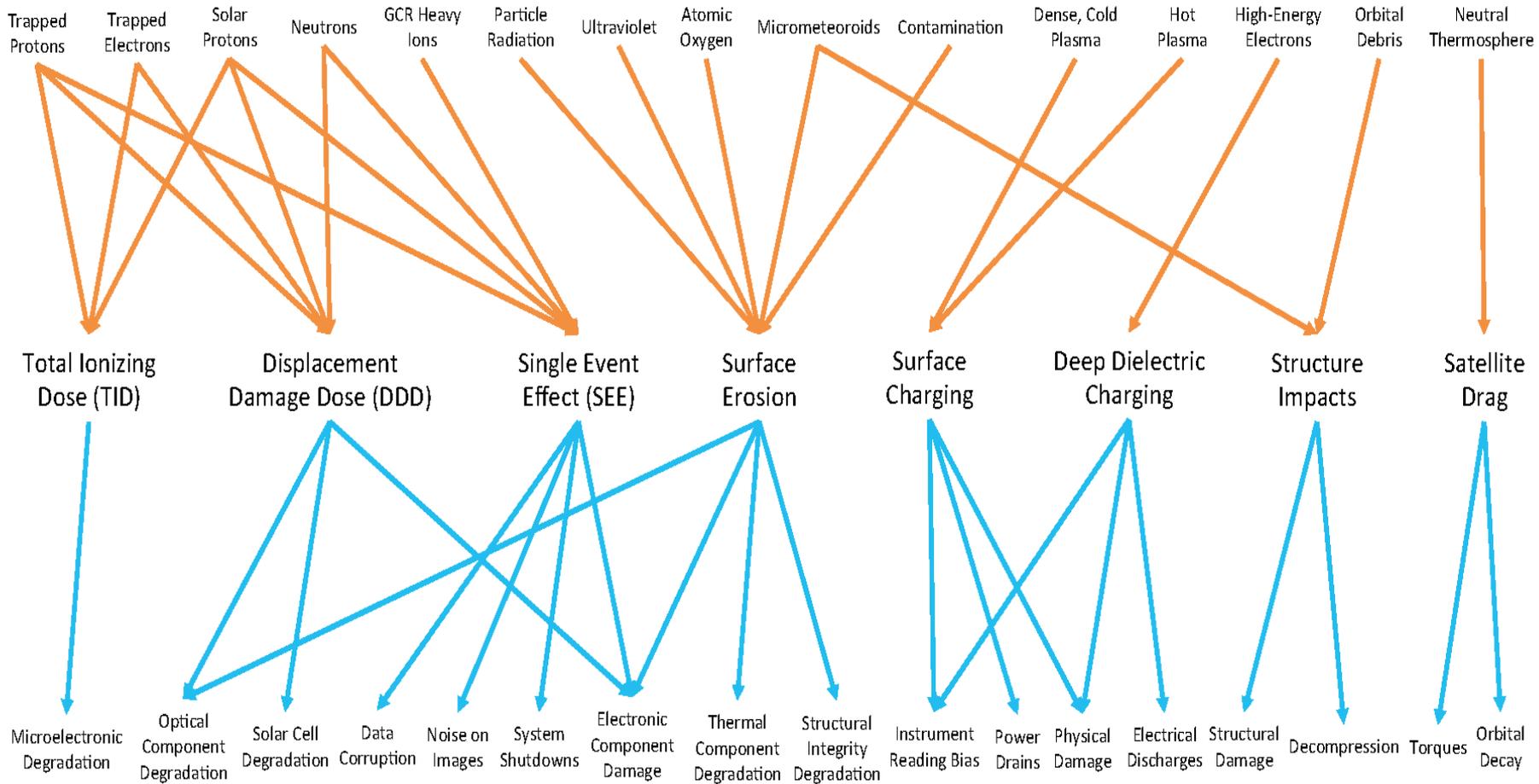
Trapped Protons Trapped Electrons Solar Protons Neutrons GCR Heavy Ions Particle Radiation Ultraviolet Atomic Oxygen Micrometeoroids Contamination Dense, Cold Plasma Hot Plasma High-Energy Electrons Orbital Debris Neutral Thermosphere

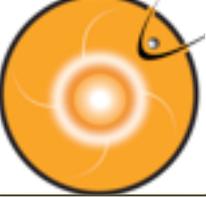
Mechanism

Total Ionizing Dose (TID) Displacement Damage Dose (DDD) Single Event Effect (SEE) Surface Erosion Surface Charging Deep Dielectric Charging Structure Impacts Satellite Drag

Effect

Microelectronic Degradation Optical Component Degradation Solar Cell Degradation Data Corruption Noise on Images System Shutdowns Electronic Component Damage Thermal Component Degradation Structural Integrity Degradation Instrument Reading Bias Power Drains Physical Damage Electrical Discharges Structural Damage Decompression Torques Orbital Decay

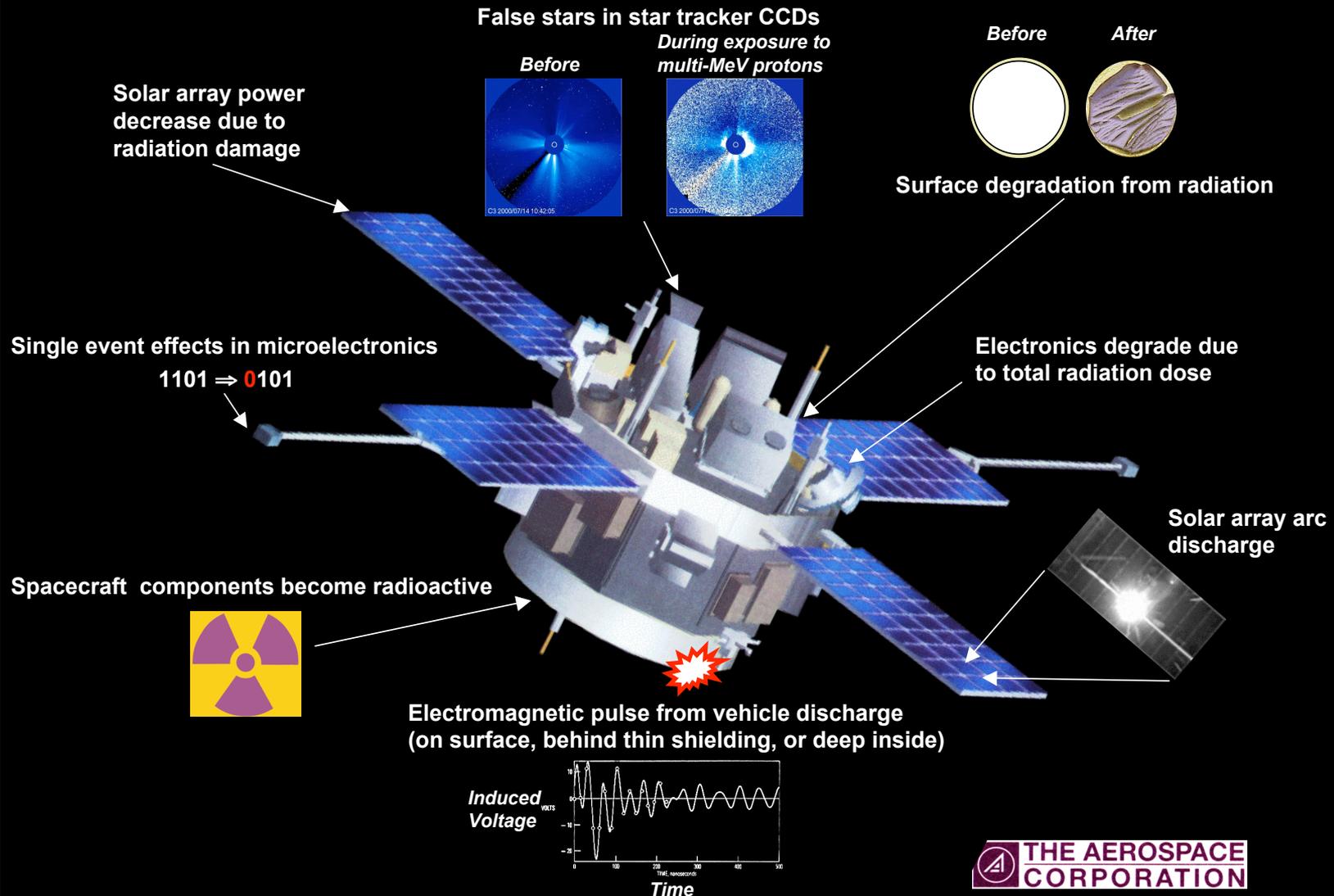


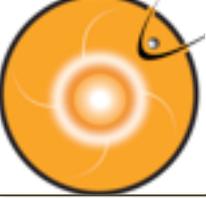


Visual representation of space environment hazards



Major Space Environment Hazards

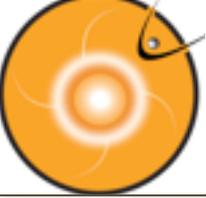




Space Environment Effects



| Space Environmental Impacts on Space Systems | | | |
|--|-------------------|---------------|------------------------|
| Anomaly Diagnosis | Koons et al, 2000 | NGDC DB, 2006 | Satellite Digest, 2014 |
| ESD-Internal, surface, and indeterminate | 54% | 31% | 10% |
| SEU (GCR, SPE, SAA, etc.) | 28% | 17% | 5% |
| Radiation Dose | 5% | --- | --- |
| Meteoroids and Orbital Debris | 3% | --- | 5% |
| Atomic Oxygen | < 1% | --- | --- |
| Atmospheric Drag | < 1% | --- | --- |
| Design | --- | --- | 25% |
| Other or Unknown | 8% | 52% | 55% |



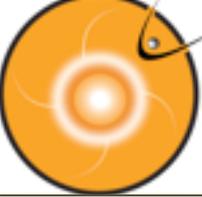
Space Environment Anomalies



- According to a study by the Aerospace Corporation the **2 most common types of spacecraft anomalies by far are due to electrostatic discharge (ESD) and single event effects (SEE)**
- Reported results*:

| Anomaly Type: | Number of Occurrences: |
|-----------------------|------------------------|
| ESD | 162 |
| SEE | 85 |
| Total Dose and Damage | 16 |
| Miscellaneous | 36 |

* H.C. Koons et al., 6th Spacecraft Technology Conference, AFRL-VS-TR-20001578, Sept. 2000



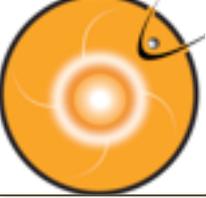
2003 Halloween Storm Impacts on Spacecraft (3)



- **Oct 28-31:**
 - CDS instrument on *SOHO* spacecraft at L1 commanded into safe mode for 3 days
 - *Mars Odyssey* spacecraft entered safe mode, MARIE instrument had a temperature red alarm leading it to be powered off (Oct. 28). S/C memory error during downloading on 29 Oct corrected with a cold reboot on Oct. 31
 - Both *Mars Explorer Rover* spacecraft entered “sun idle” mode due to excessive start tracker events
- **Oct 29:**
 - NASA’s Earth Sciences Mission Office directed all instruments on 5 spacecraft be turned off or safed due to Level 5 storm prediction. Satellites affected include *AQUA*, *Landsat*, *TERRA*, *TOMS*, and *TRMM*
- **Oct 30:**
 - *ACE & Wind* solar wind satellites lost plasma observations
 - Electron sensors of *GOES* satellite in geosynchronous orbit saturated
- **Nov 2:**
 - *Chandra* observations halted again autonomously due to radiation. Resumption of observations delayed for days
- **Nov. 6:**
 - *Polar* TIDE instrument reset itself and high voltage supplies were disabled; recovered within 24 hr.
 - *Mars Odyssey* spacecraft commanded out of Safe mode; operations nominal.

adapted from Allen and Wilkerson, 2010

http://www.ngdc.noaa.gov/stp/satellite/anomaly/2010_sctc/docs/1-1_JAllen.pdf

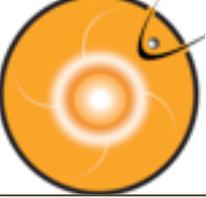


Seven types SWx impacts for NASA's robotic missions

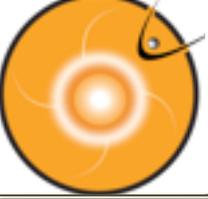


1. **Spacecraft surface charging caused by low-energy (< 100 keV) electrons**, which are abundant, for example, in the inner magnetosphere during magnetospheric substorms.
2. **Spacecraft internal electrostatic discharge caused by high-energy electrons (> 100 keV)** that exist, for example, in the dynamic outer radiation belt of the Earth.
3. **Single event effects due to high-energy (> 10 MeV) protons and heavier ions** generated, for example, in solar flares and in coronal mass ejection (CME) shock fronts.
4. **Total dosage effects caused by cumulative charged particle radiation** received by spacecraft.
5. **Increased spacecraft drag caused by the thermal expansion of the Earth's upper atmosphere** during space weather storms.
6. **Communication disruptions between ground stations and spacecraft** due to ionospheric irregularities
7. **Attitude control disruptions caused, for example, by large storm-time magnetic field fluctuations** in the geostationary orbit.

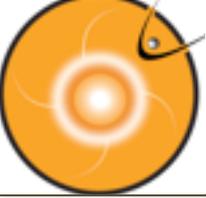
Feedback from our annual SWx workshop for robotic missions



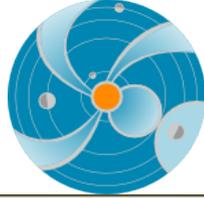
- low-energy protons (< 10 MeV) pose a problem due to trapping into charge-coupled device (CCD) substrates.
- ➔ virtually any part of electron and ion spectra ranging from low to relativistic energies can impact spacecraft operations.



A few types of space weather impacts on spacecraft impacts



Surface Charging

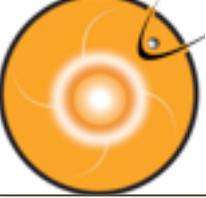


Surface charging: which can lead to electrostatic discharges (ESD),

ESD: can lead to a variety of problems, including component failure and phantom commands in spacecraft electronics [Purvis et al., 1984].

Purvis, C. K., H. B. Garrett, A. C. Wittlesey, and N. J. Stevens (1984), Design guidelines for assessing and controlling spacecraft charging effects, NASA Tech. Pap. 2361

<https://standards.nasa.gov/documents/detail/3314877>



Surface Charging



Commercial satellite anomaly

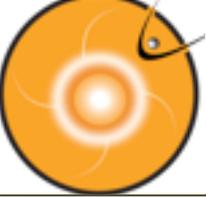
Substorm injections (Aurora)

More often in the midnight to morning sector

<100 keV e- distribution: similar behavior as spacecraft anomalies

=> Surface charging might be the main cause of the anomalies.

Choi, H.-S., J. Lee, K.-S. Cho, Y.-S. Kwak, I.-H. Cho, Y.-D. Park, Y.-H. Kim, D. N. Baker, G. D. Reeves, and D.-K. Lee (2011), Analysis of GEO spacecraft anomalies: Space weather relationships, Space Weather, 9, S06001, doi:10.1029/2010SW000597.



Surface Charging Hazards distribution

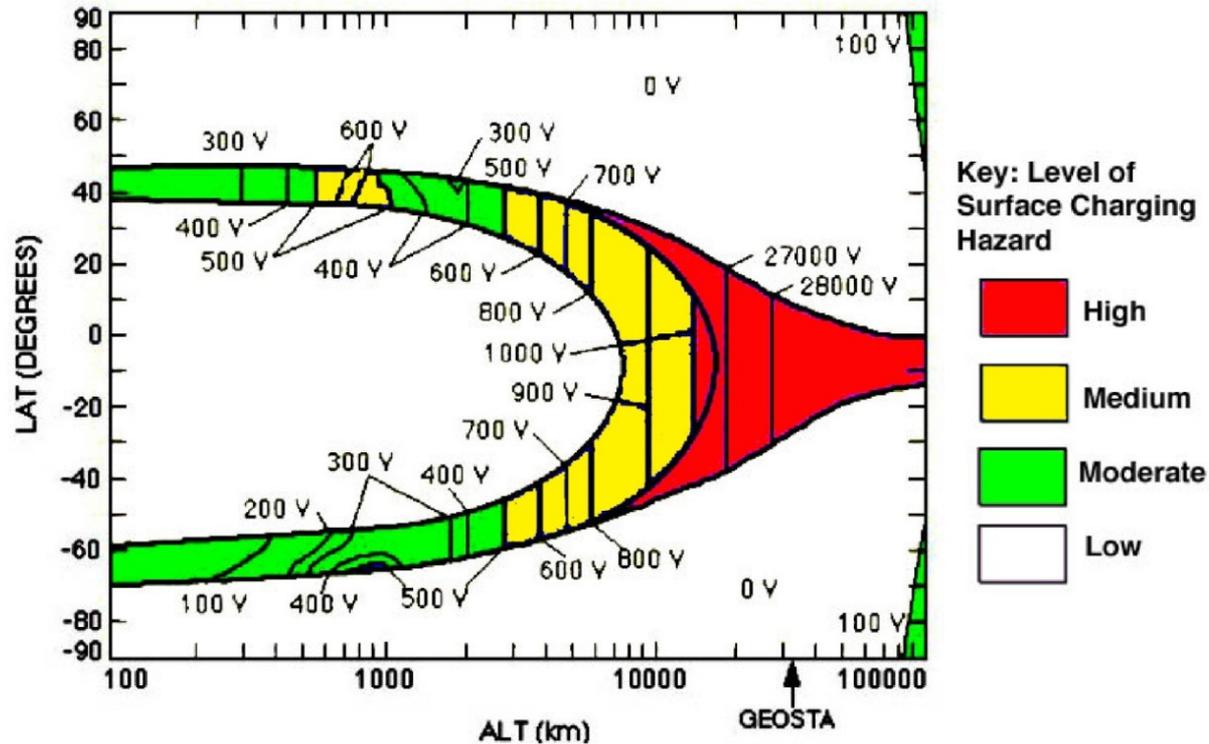
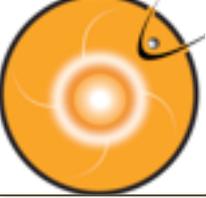


Figure 1—Earth Regimes of Concern for On-Orbit Surface Charging Hazards for Spacecraft Passing Through Indicated Latitude and Altitude (Evans and others (1989))



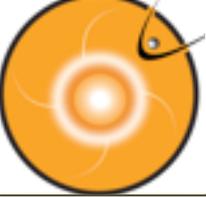
Title: Mitigating In-Space Charging Effects-A
Guideline

Document Date: 2011-03-03

Revalid and Reaffirmed Date: 2016-03-03

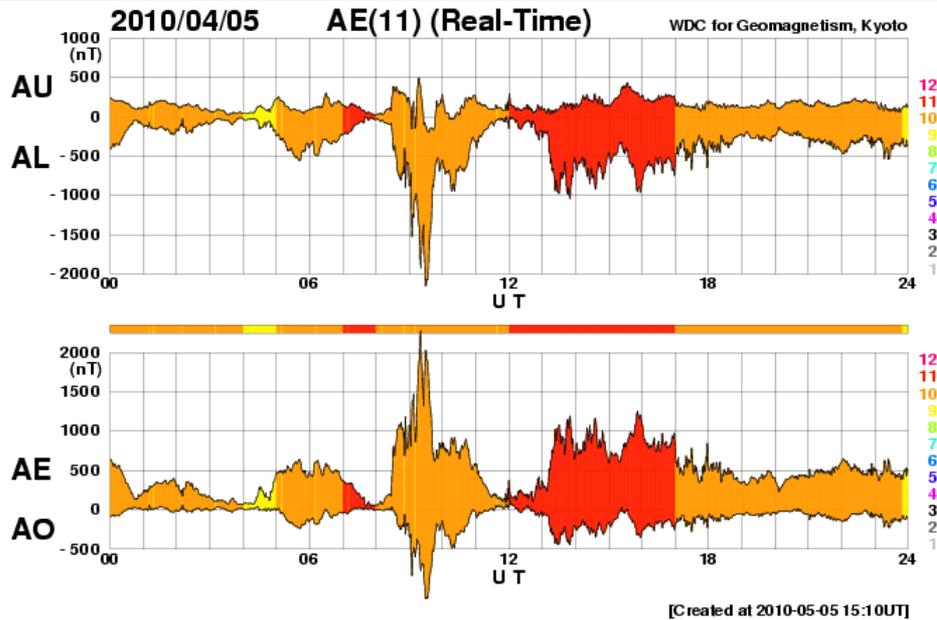
Revision: A

Organization: NASA

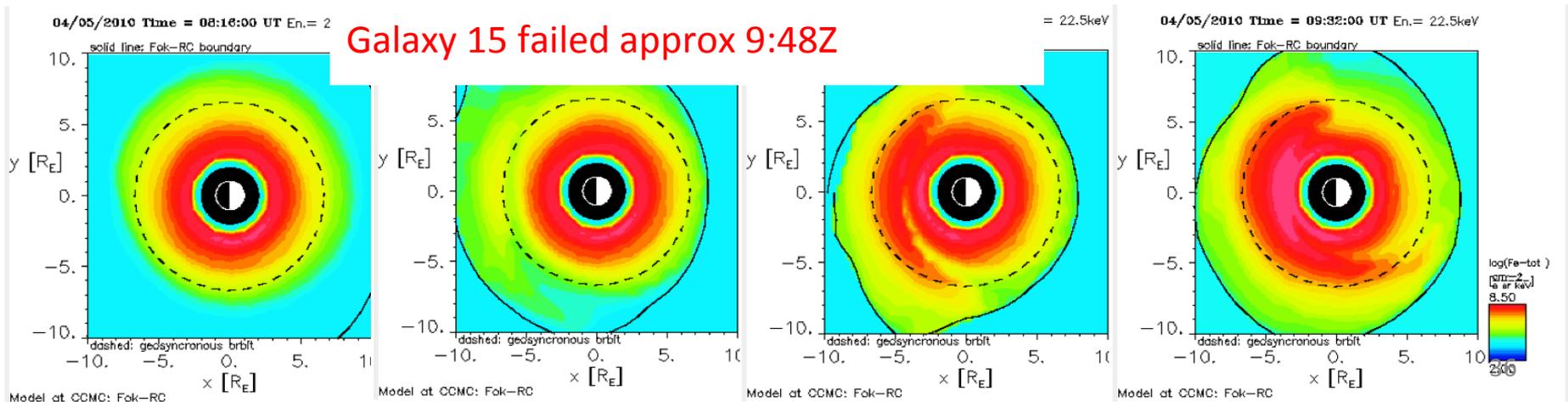


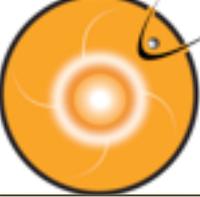
Galaxy 15 failure on April 5, 2010

- surface charging might play a role

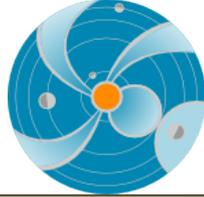


22keV electrons 4/5, 8:16-9:32Z

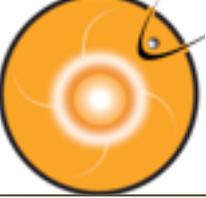




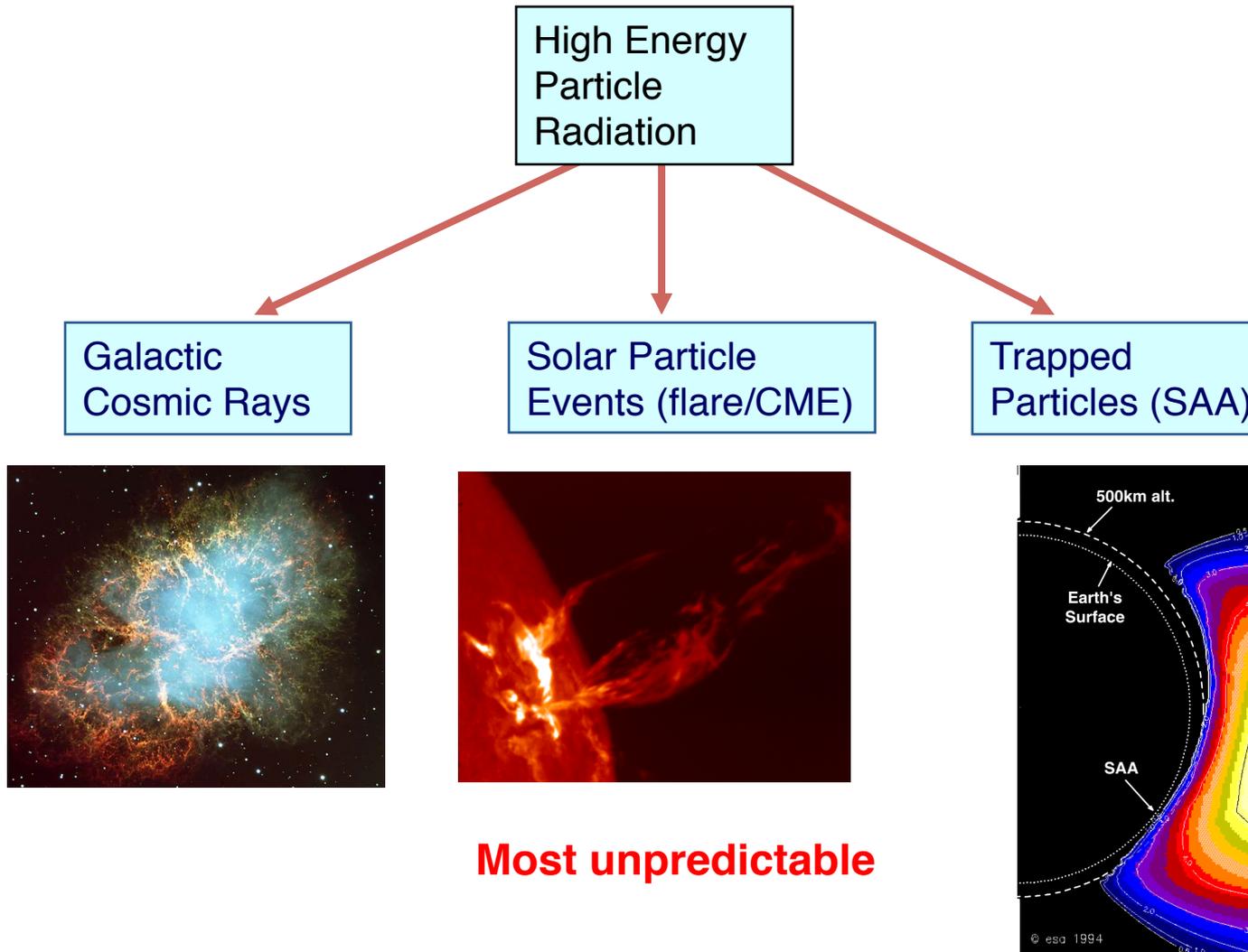
Environmental Source of Single Event Effects



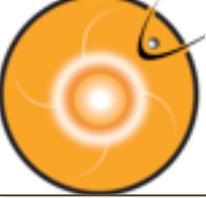
- Single Event Environments in Space
 - Galactic Cosmic Rays
 - Solar Particle Events (flare/CME)
 - Trapped Protons in the inner belt (1 – 3 RE)
 - High energy neutrons



SEE source in Space



Most unpredictable



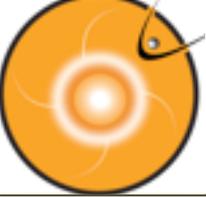
Galactic Cosmic Rays



- Galactic cosmic rays (GCR) are high-energy charged particles that originate outside our solar system.
- Supernova explosions are a significant source

Anticorrelation with solar activity
More pronounced/
intense during solar minimum

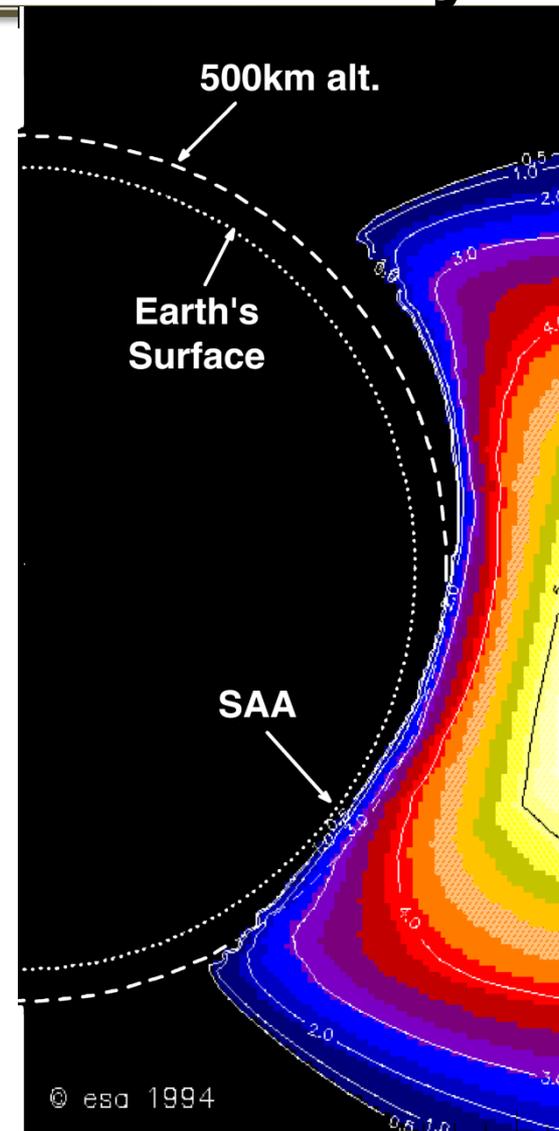


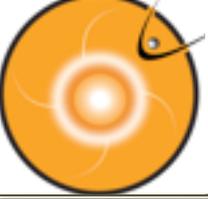


South Atlantic Anomaly

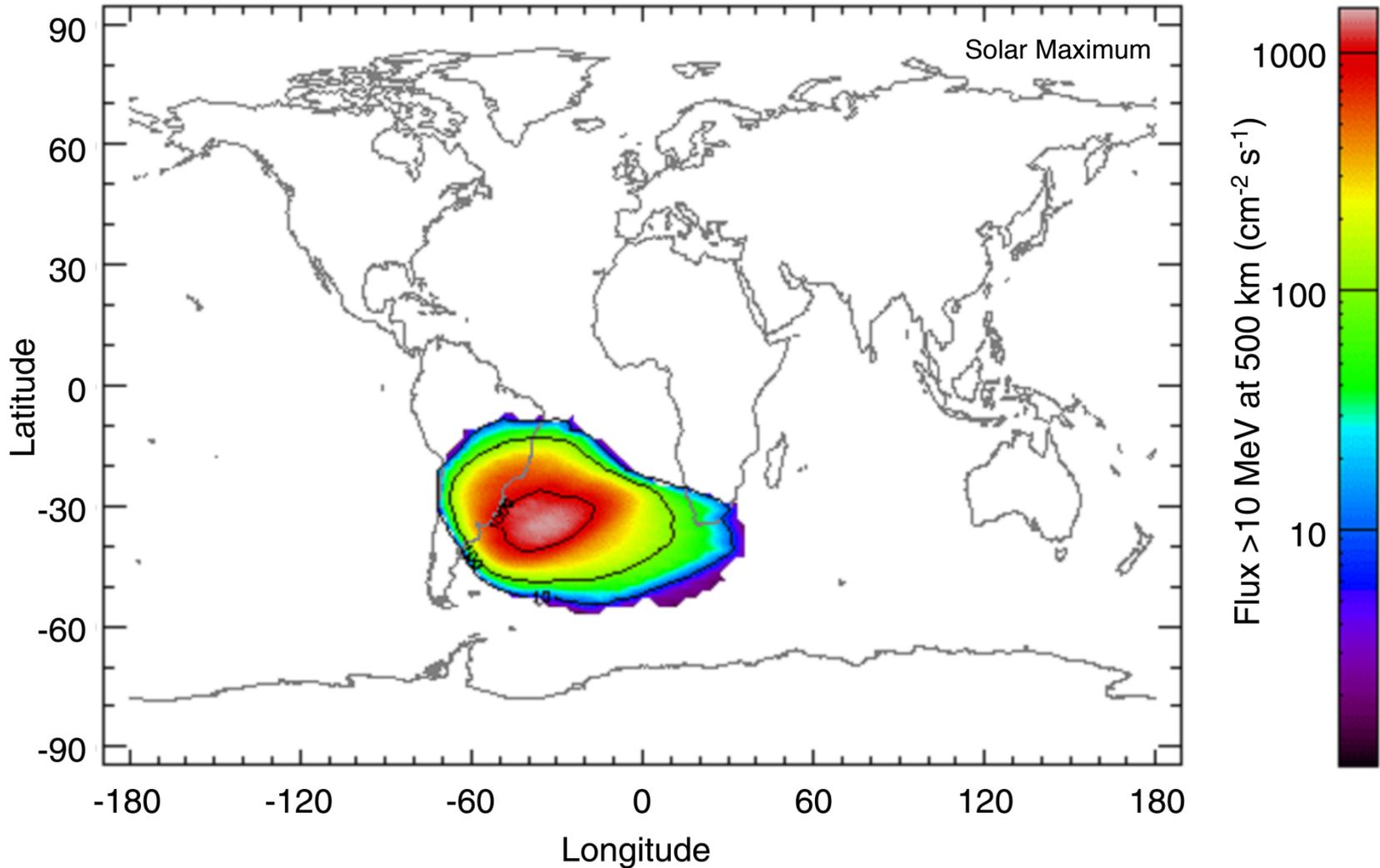


- Dominates the radiation environment for altitudes less than about 1000 km.
- Caused by tilt and shift of geomagnetic axis relative to rotational axis.
- Inner edge of proton belt is at lower altitudes south and east of Brazil.

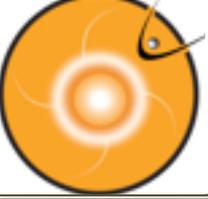




South Atlantic Anomaly



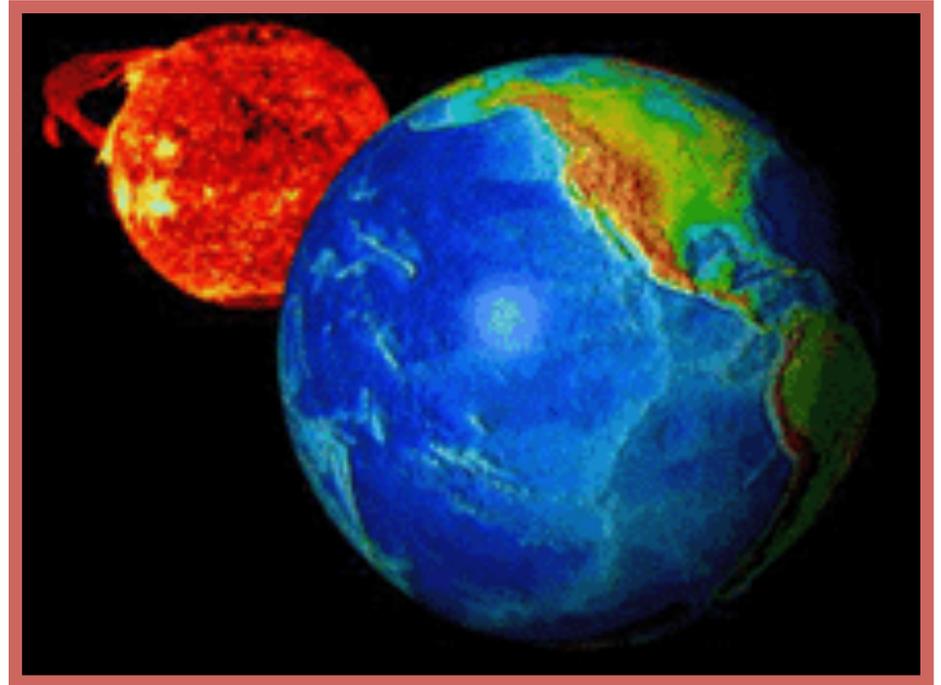
From SPENVIS, <http://www.spenvis.oma.be/>

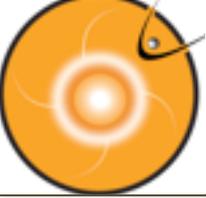


Solar Particle Events



- Caused by flare/CME

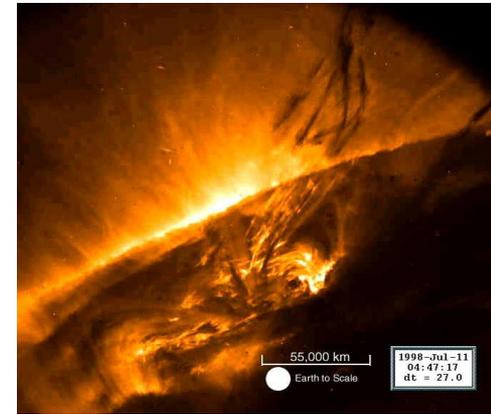
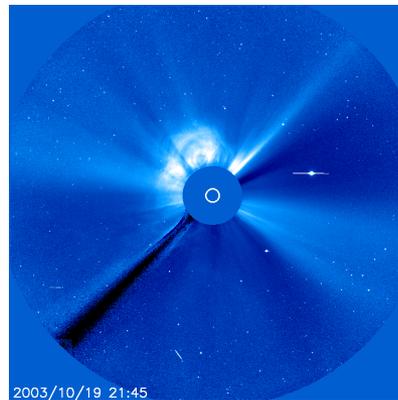
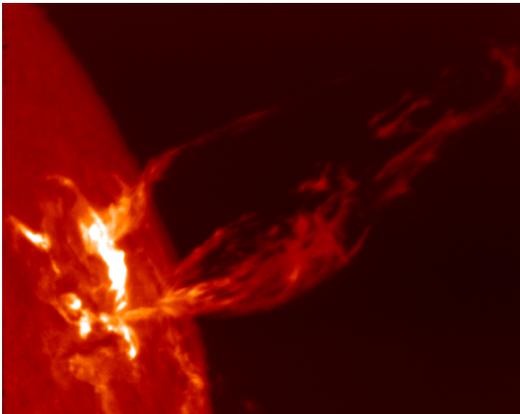


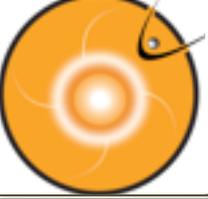


Characteristics of SEPs

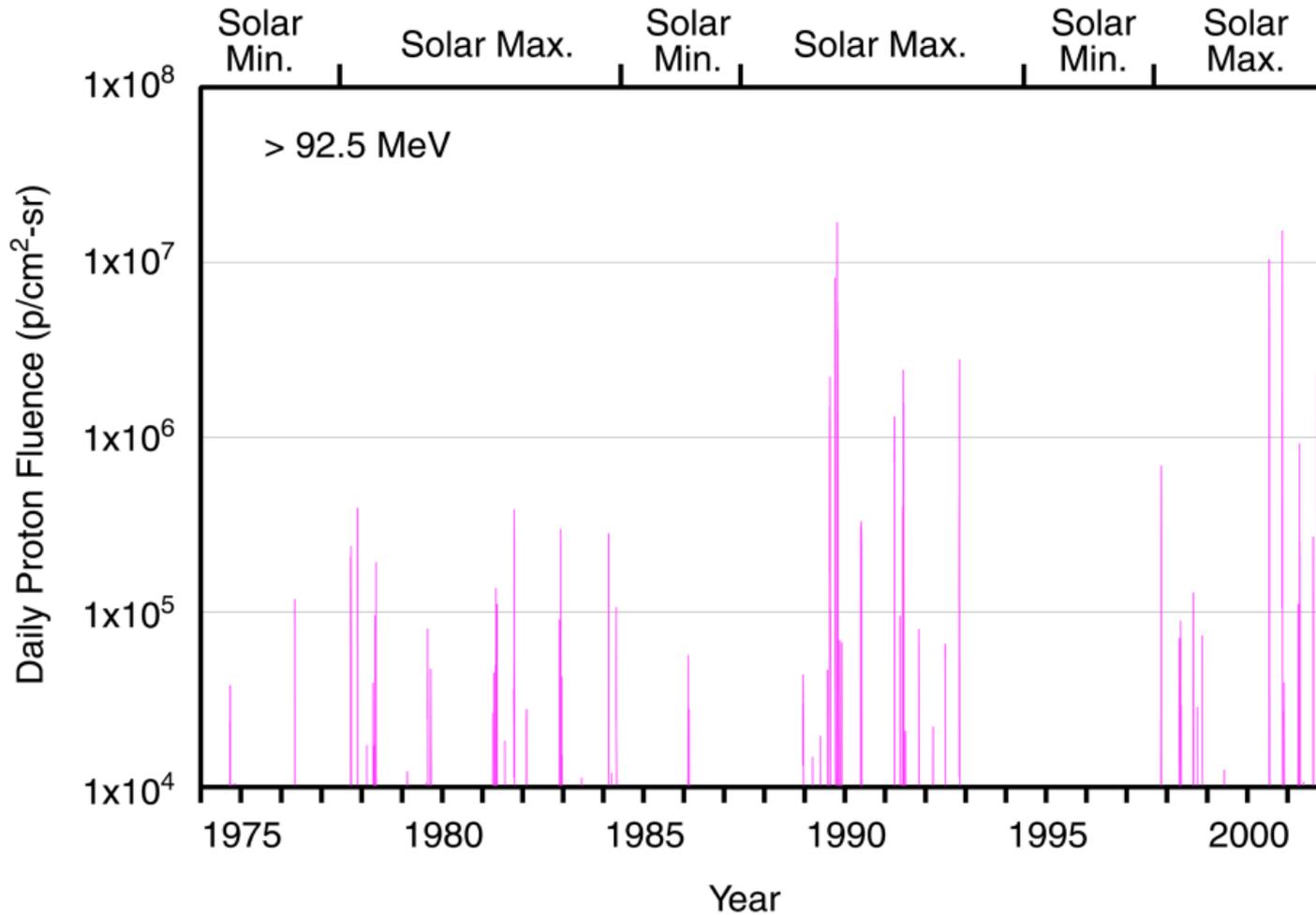
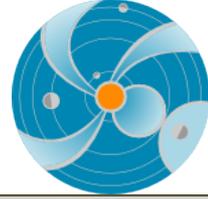


- Elemental composition* (may vary event by event)
 - 96.4% protons
 - 3.5% alpha particles
 - 0.1% heavier ions (not to be neglected!)
- Energies: up to \sim GeV/nucleon
- Event magnitudes:
 - > 10 MeV/nucleon integral fluence: can exceed 10^9 cm^{-2}
 - > 10 MeV/nucleon peak flux: can exceed 10^5 $\text{cm}^{-2}\text{s}^{-1}$

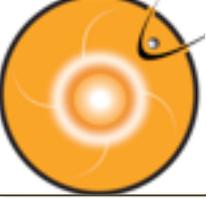




Solar Cycle Dependence



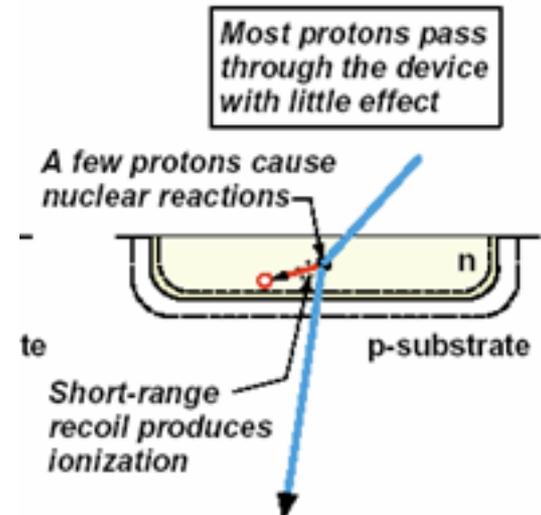
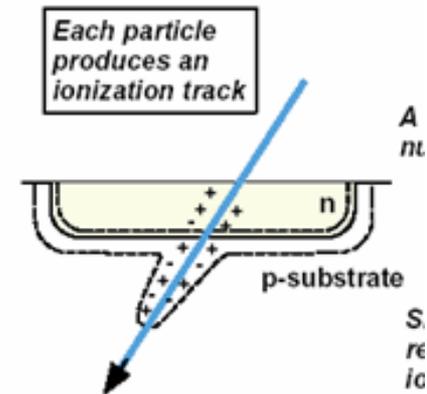
Most unpredictable

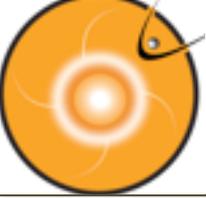


Single Event Effects (SEE)



- **Single event effect (SEE)** : current generated by ion passing through the sensitive volume of a biased electronic device changes the device operating state
- **SEE Generated by Heavy Ions (Z=2-92)**
- High linear energy transfer (LET) rate of heavy ions produces ionization along track as ion slows down
- Dense ionization track over a short range produces sufficient charge in sensitive volume to cause SEE
- SEE is caused directly by ionization produced by incident heavy ion particles
- **SEE Generated by Protons (Z=1)**
- Proton LET is too low to generate SEE, but secondary heavy ions are produced in nuclear reactions with nuclei of atoms (usually silicon) inside electronics. Energy is transferred to a target atom fragment or recoil ion with high LET and charge deposited by recoil ion(s) is the direct cause of SEE.
- Only a small fraction of protons are converted to such secondary particles (1 in 10^4 to 10^5).

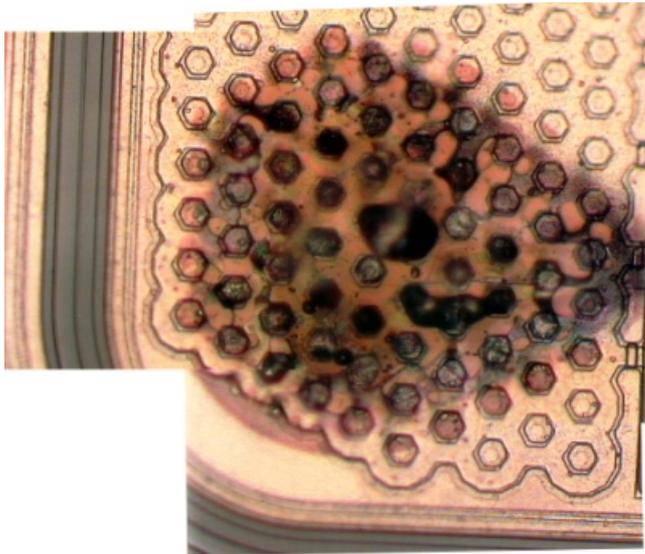




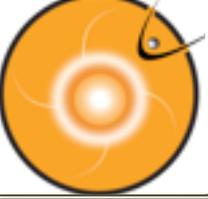
What is a Single Event Effect?



- Single Event Effect (SEE) – any measureable effect in a circuit caused by single incident ion
 - Non-destructive – SEU (Single Event Upset), SET (single event transients), MBU (Multiple Bit Upsets), SHE (single-event hard error)
 - Destructive – SEL (single event latchup), SEGR (single event gate rupture), SEB (single event burnout)



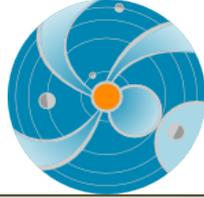
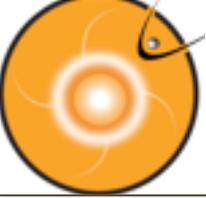
*Destructive event
in a COTS 120V
DC-DC Converter*



Single Event Upsets

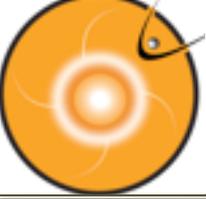


- SEUs: are soft errors, and non-destructive. They normally appear as transient pulses in logic or support circuitry, or as bitflips in memory cells or registers.



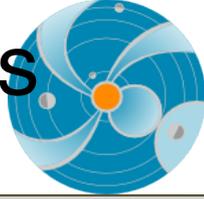
Destructive SEEs

- Several types of hard errors, potentially destructive, can appear:
- Single Event Latchup (SEL) results in a high operating current, above device specifications, and must be cleared by a power reset.
- Other hard errors include Burnout of power MOSFETS (Metal Oxide Semiconductor Field-Effect Transistor) , Gate Rupture, frozen bits, and noise in CCDs.



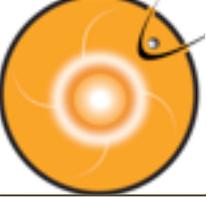
Anomalies March 2012 SWx events

SEEs dominate



- Quite a few NASA spacecraft experienced anomalies, majority of which are SEEs. Some of them required reset/reboot.

Details to be discussed later.



Internal Charging

- energetic electrons in the outer radiation belt

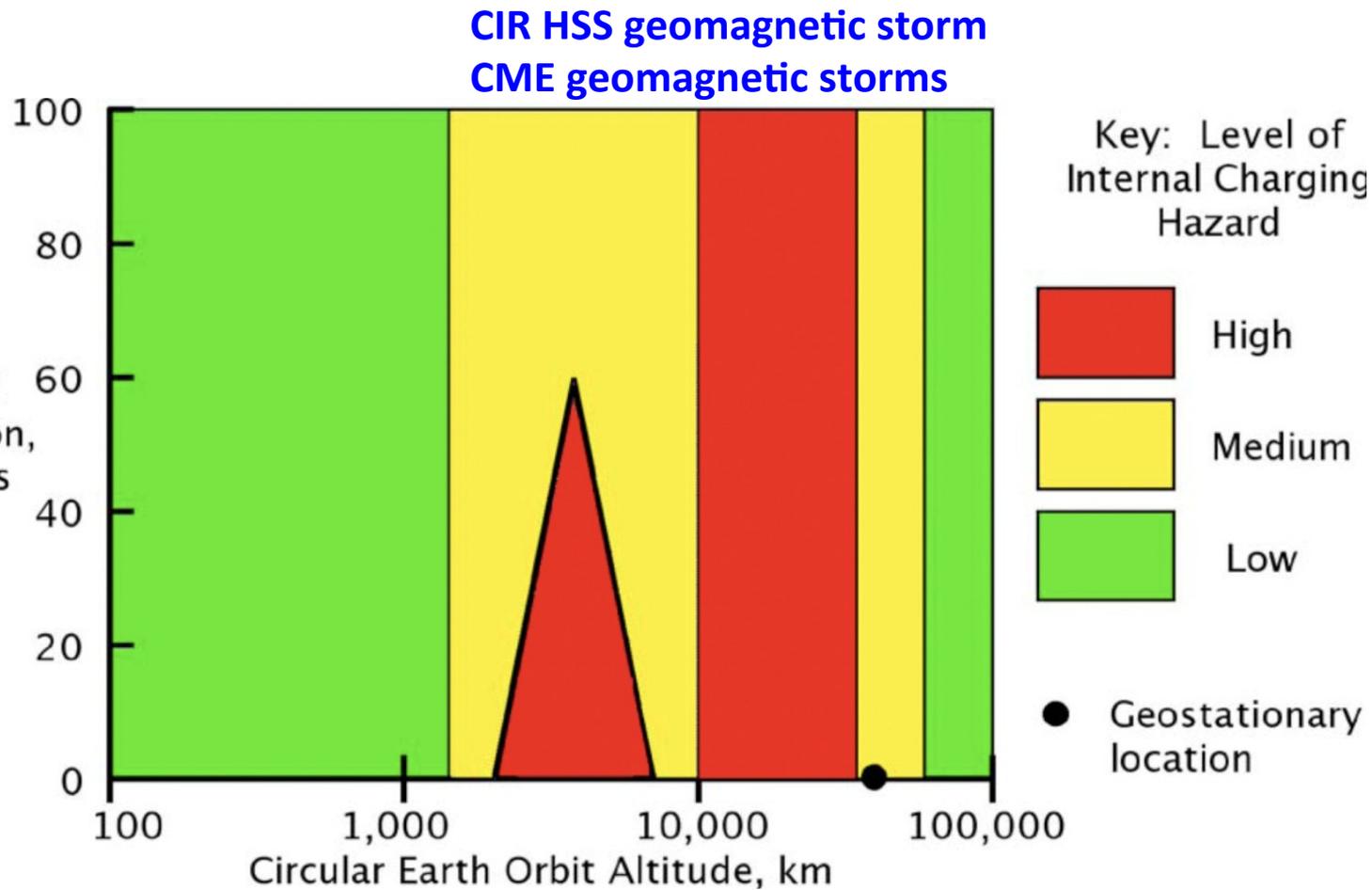
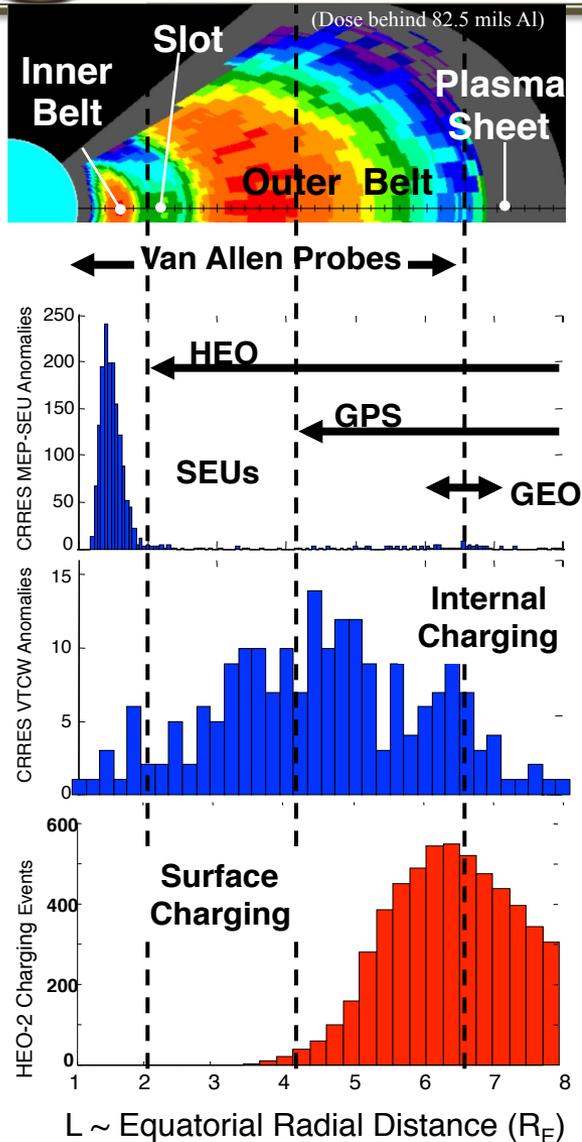


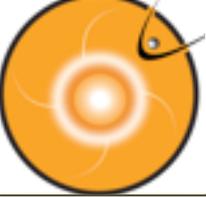
Figure 2—Earth Regimes of Concern for On-Orbit Internal Charging Hazards for Spacecraft with Circular Orbits



Space Environment Hazards (different types of charging) for Spacecraft in the near-Earth environment



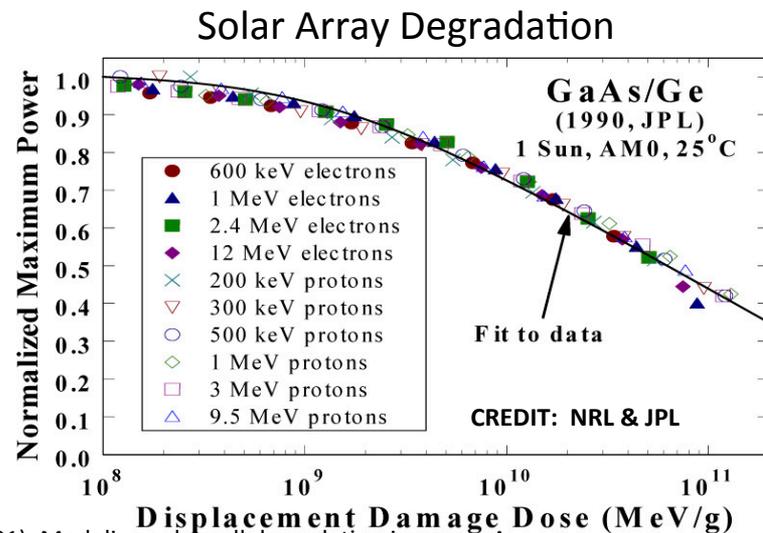
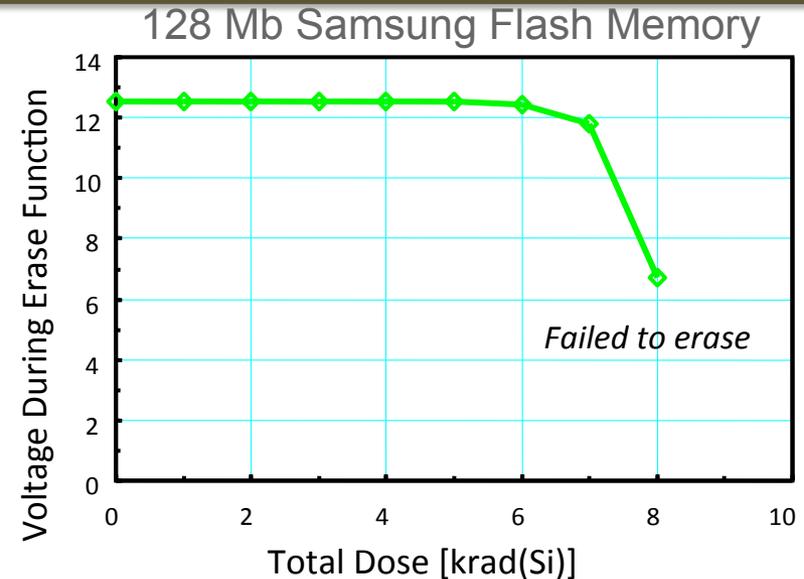
- Single Event Effects tend to occur in the inner (proton) belt and at higher L shells when a solar particle event is in progress.
- Internal electrostatic discharges (ESD) occur over a broad range of L values corresponding to the outer belt, where penetrating electron fluxes are high (300 keV – few MeV electrons)
- Surface ESD tends to occur when the spacecraft or surface potential is elevated: at 2000-0800 local time in the plasma sheet and in regions of intense field-aligned currents (auroral zone) (few eV – 50 keV) - plasma sheet, ring current, aurora zone, magnetosheath
- Event Total Dose occurs primarily in orbits that rarely see trapped protons in the 1-20 MeV range (e.g., GEO, GPS) because these are the orbits for which solar particle events and transient belts make up a majority of the proton dose (including displacement damage)

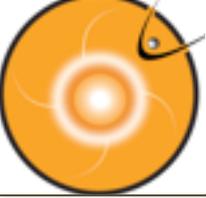


Total Dose Effects

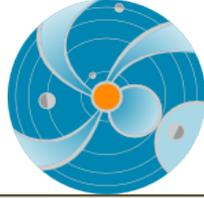
- Total Ionizing Dose (TID) – cumulative damage resulting from ionization (electron-hole pair formation) causing
 - Threshold voltage shifts
 - Timing skews
 - Leakage currents
- Displacement Damage Dose (DDD) – cumulative damage resulting from displacement of atoms in semiconductor lattice structure causing:
 - Carrier lifetime shortening
 - Mobility degradation

DDD can also be referred to in the context of Non-Ionizing Energy Loss (NIEL)





Human Safety in Space

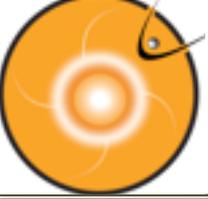


- GCR
- **SEP**

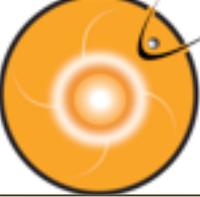
Johnson Space Center/Space Radiation
Analysis Group (SRAG)

Limit: the > 100 MeV flux exceeding 1 pfu
(1 pfu = 1 particle flux unit = $1/\text{cm}^2/\text{sec}/\text{sr}$)

- All clear (EVA –extravehicular activity)



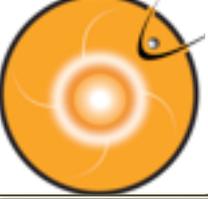
Examples of space environment effects on satellites



2003 Halloween Storm Impacts on Spacecraft (1)



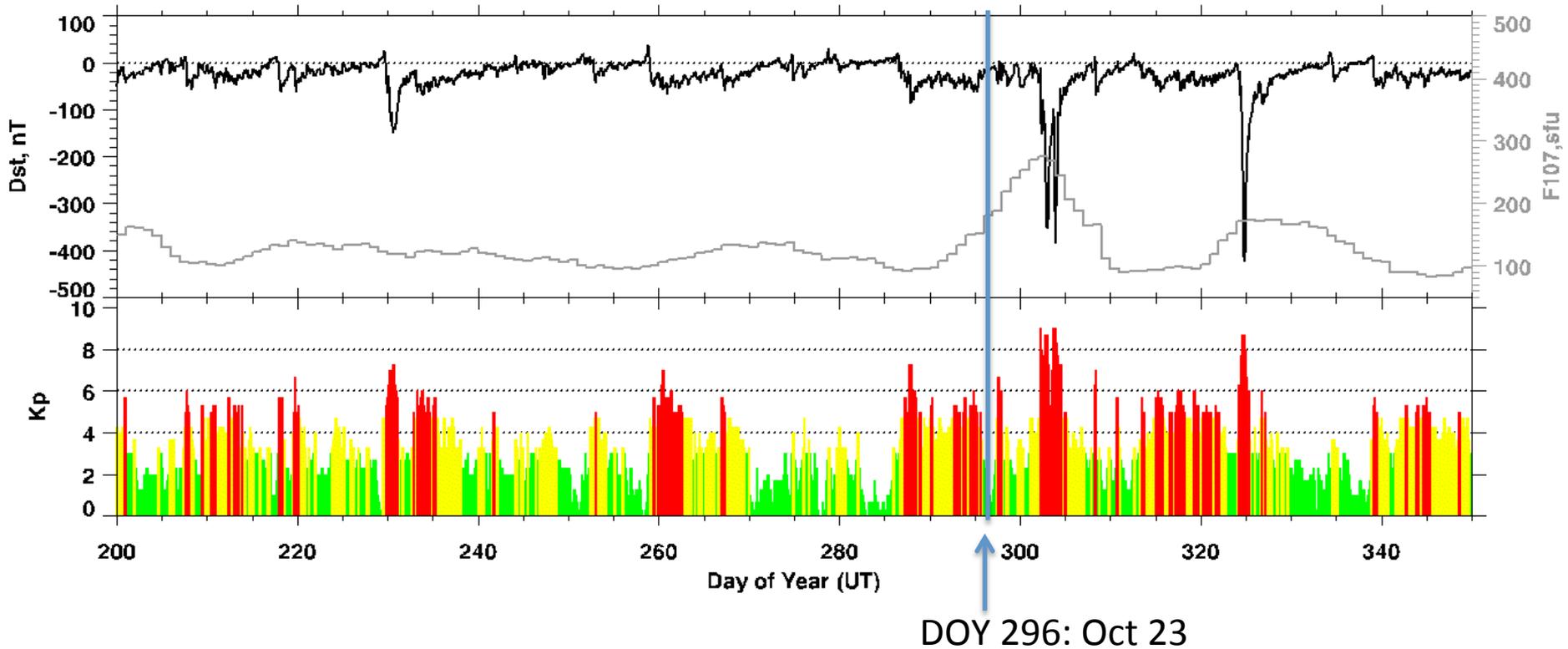
- **Oct 23:**
 - ***Genesis*** satellite at L1 entered safe mode, normal operations resumed on Nov. 3.
 - ***Midori-2(ADEOS-2)*** Earth-observing satellite power system failed, safe mode, telemetry lost (23:55), spacecraft lost
- **Oct 24:**
 - ***Stardust*** comet mission went into safe mode due to read errors; recovered.
 - ***Chandra X-ray Observatory*** astronomy satellite observations halted due to high radiation levels (09:34EDT), restarted Oct. 25
 - ***GOES-9, 10 and 12*** had high bit error rates (9 and 10), magnetic torquers disabled due to geomagnetic activity
- **Oct 25:**
 - ***RHESSI*** solar satellite had spontaneous CPU reset (10:42)
- **Oct 26:**
 - ***SMART-1*** had auto shutdown of engine due to increased radiation level in lunar transfer orbit (19:23)
- **Oct 27:**
 - ***NOAA-17AMSU-A1*** lost scanner
 - ***GOES-8*** X-ray sensor turned itself off and could not be recovered
- **Oct 28-30:**
 - Astronauts on ***Intl. Space Station*** went into service module for radiation protection
 - Instrument on ***Integral*** satellite went into safe mode because of increased radiation
 - ***Chandra*** observations halted again autonomously, resumed Nov 1

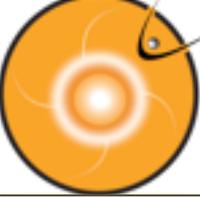


Major indices during 2003



Dst, Kp, F10.7





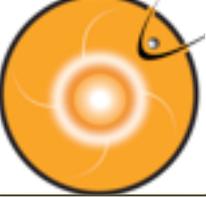
2003 Halloween Storm Impacts on Spacecraft (2)



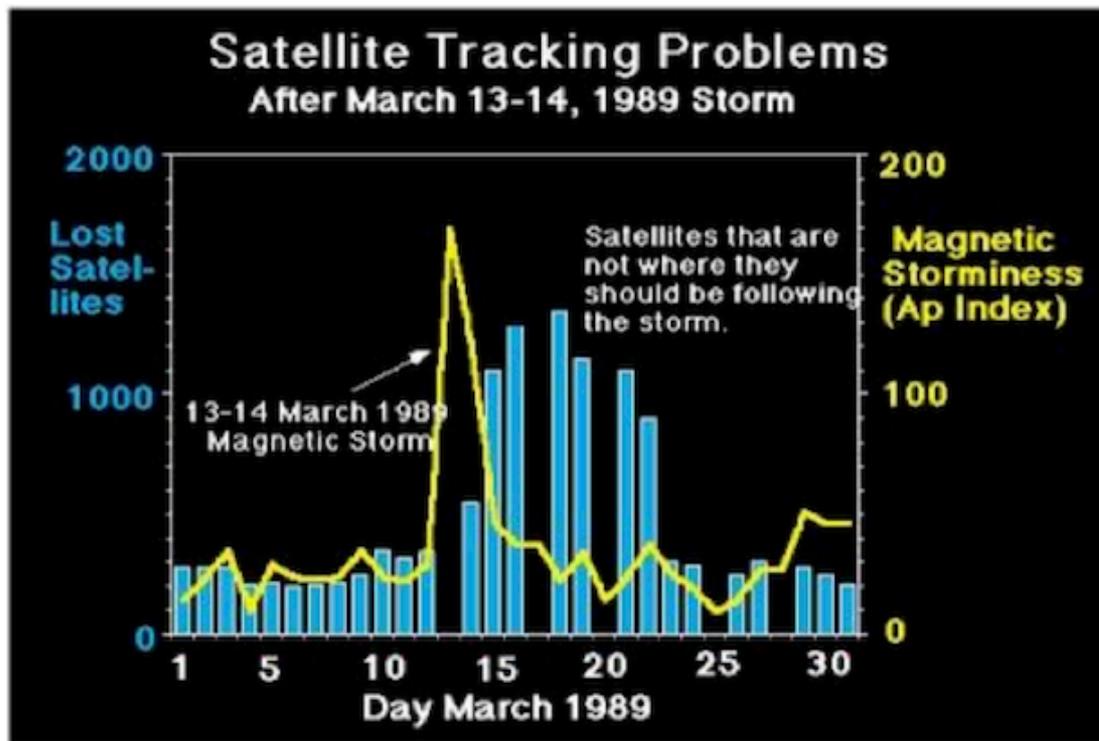
- **Oct 28:**
 - ***DMSP F16*** SSIES sensor lost data twice, on Oct. 28 and Nov. 3; recovered. microwave sounder lost oscillator; switched to redundant system
 - ***SIRTF***, in orbit drifting behind Earth, turned off science experiments and went to Earth pointing due to high proton fluxes, 4 days of operations lost
 - ***Microwave Anisotropy Probe*** spacecraft star tracker reset and backup tracker autonomously turned on, prime tracker recovered
- **Oct 29:**
 - ***Kodamadata*** relay satellite in GEO; safe mode, signals noisy, recovery unknown
 - ***RHESSI*** satellite had 2 more spontaneous resets of CPU (28, 17:40; 29, 03:32).
 - ***CHIPS*** satellite computer went offline on Oct. 29 and contact lost with the spacecraft for 18 hr. When contacted the S/C was tumbling; recovered successfully. Offline for a total of 27 hrs.
 - ***X-ray Timing Explorer*** science satellite Proportional Counter Assembly (PCA) experienced high voltages and the All Sky Monitor autonomously shut off, both instruments recovered Oct 30 but PCA again shut down. PCA recovery delayed into November.

Allen and Wilkerson, 2010

http://www.ngdc.noaa.gov/stp/satellite/anomaly/2010_sctc/docs/1-1_JAllen.pdf

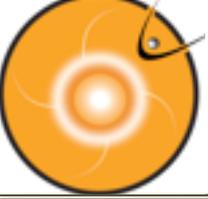


Space weather impacts on satellite positioning/tracking

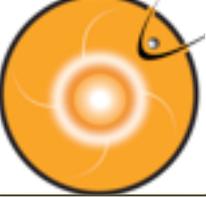


After a large geomagnetic storm in March, 1989, the North American Aerospace Defense Command (NORAD) had to re-identify hundreds of objects due to loss of tracking and compute their new orbits. During the same March 1989 storm event, for example, the NASA's Solar Maximum Mission (SMM) spacecraft had dropped its altitude as if it hit a "brick wall" due to the increased atmospheric drag.

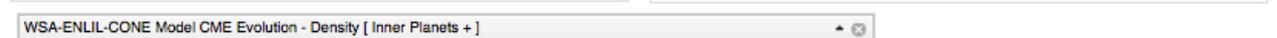
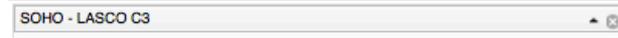
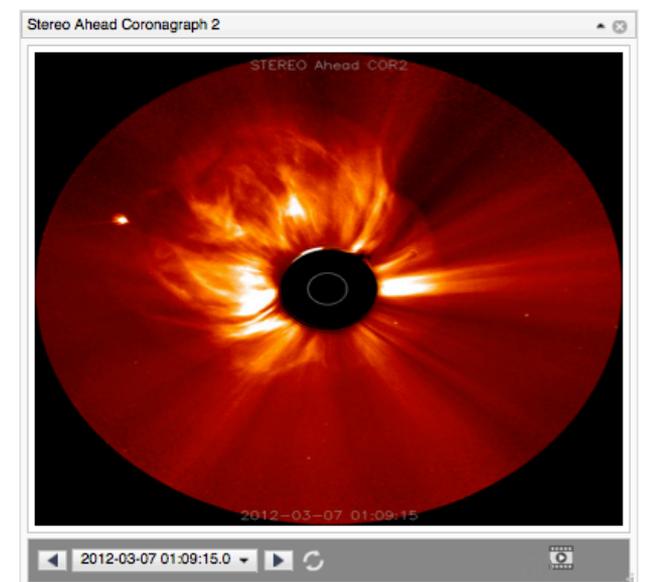
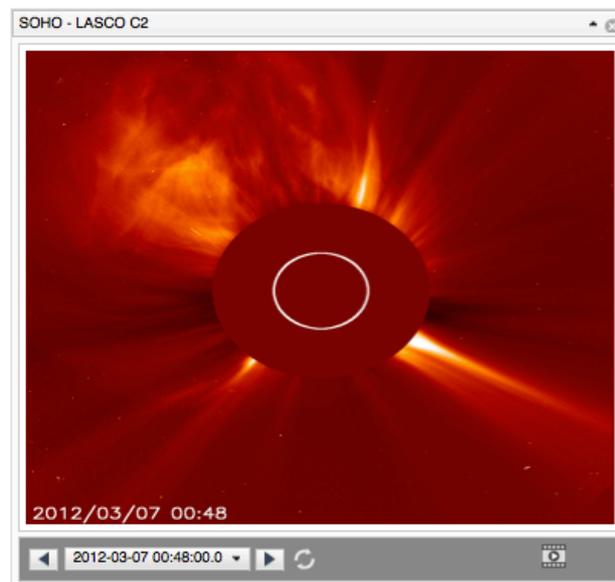
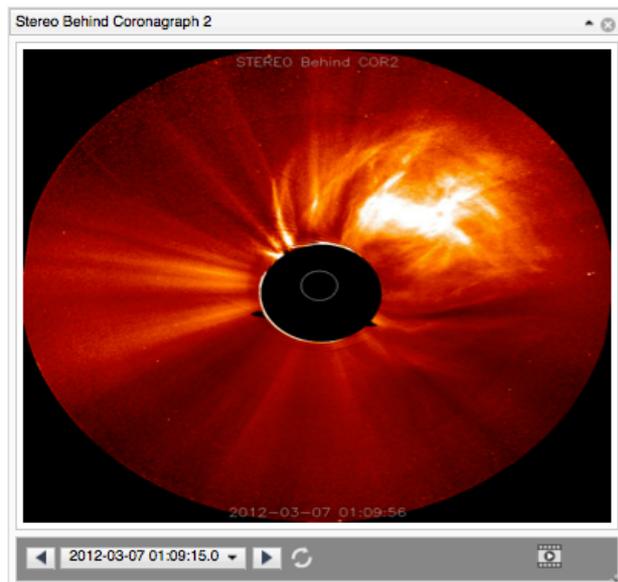
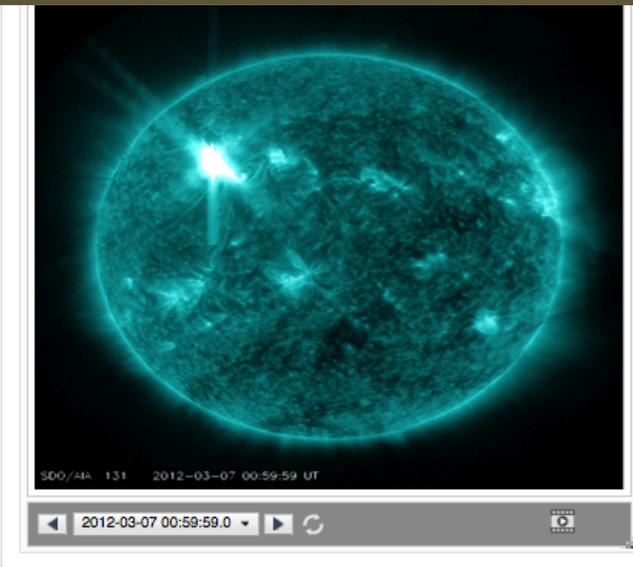
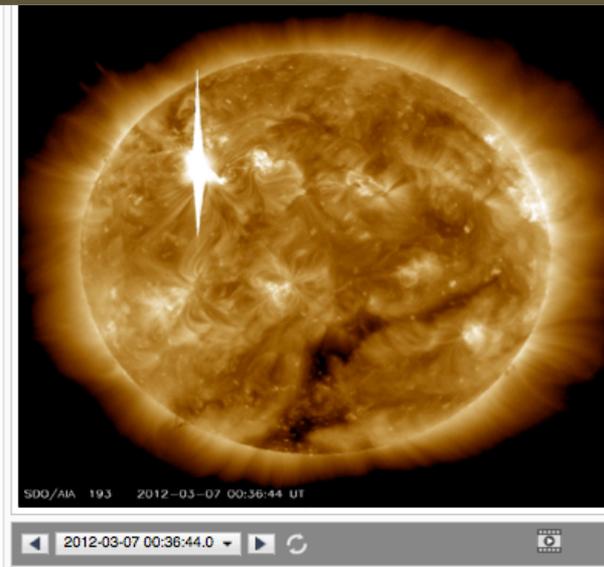
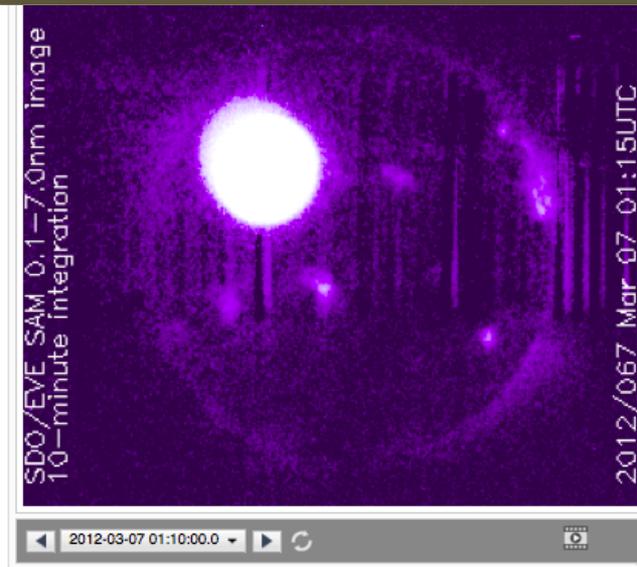
<http://www.swpc.noaa.gov/impacts/satellite-drag>

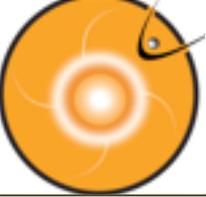


**Operator response to SWx impacts
for the March 2012 events
spacecraft specific/instrument specific**



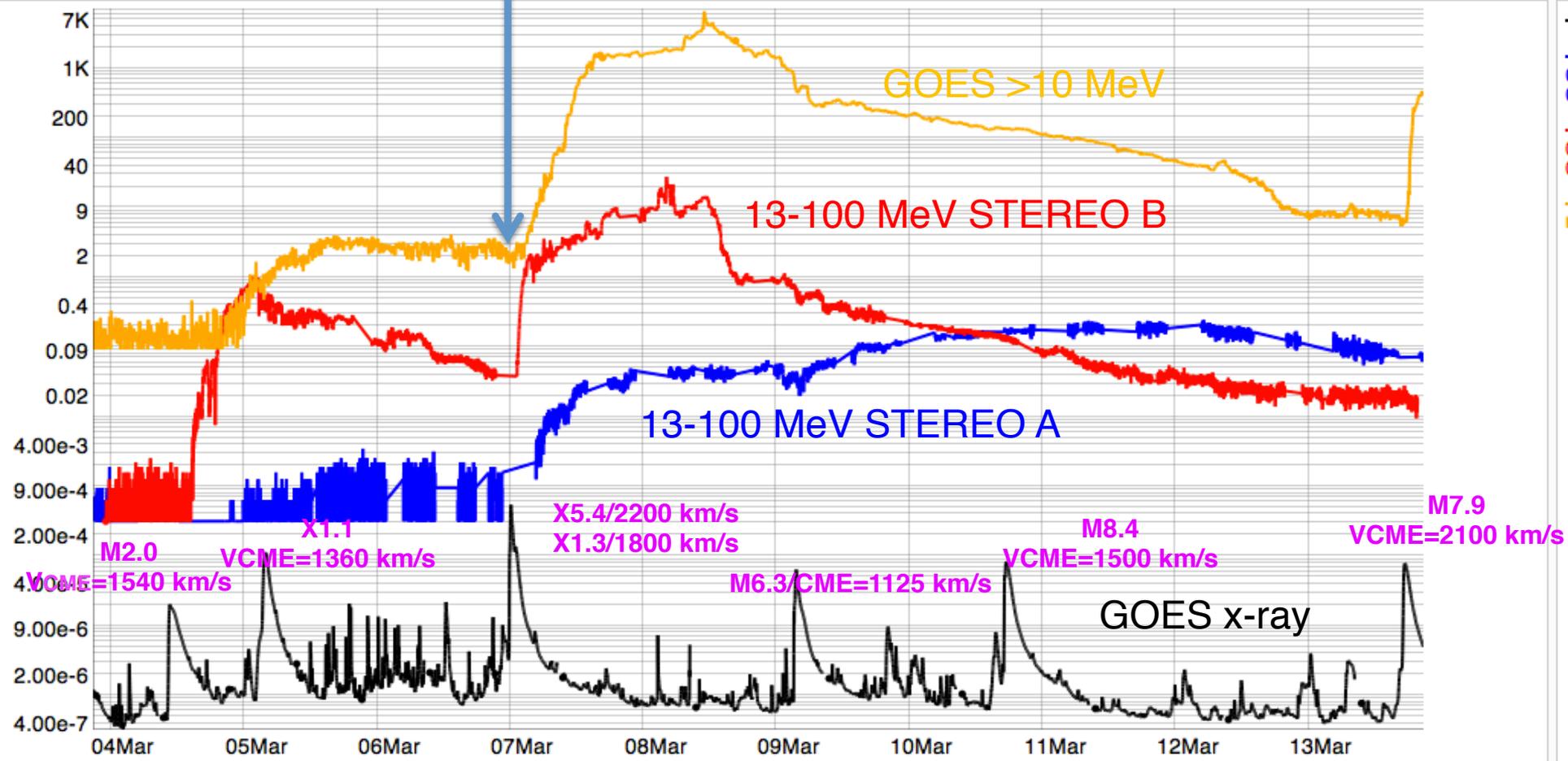
March 7 flares/CMEs

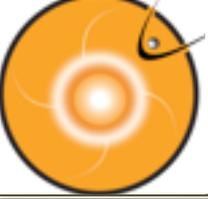




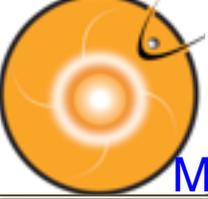
SEP: proton radiation (flare and CME)

SWA Custom Timeline Cygnet





Major events from the long- lasting AR1429 during March 4 – 28, 2012



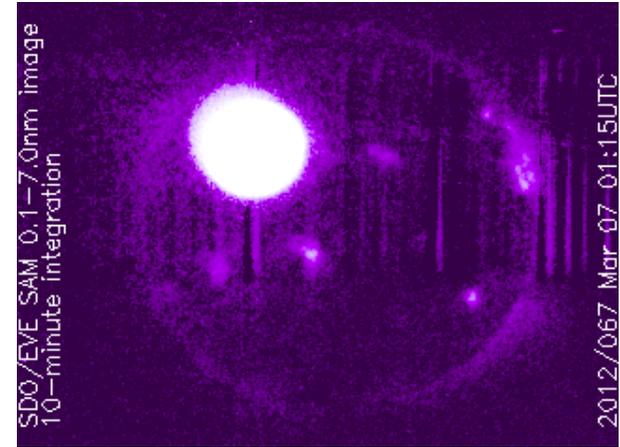
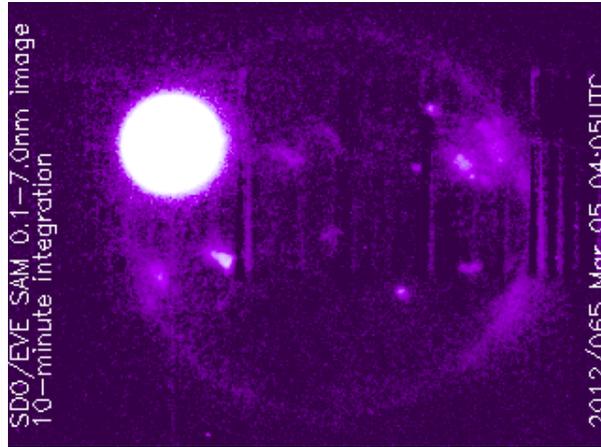
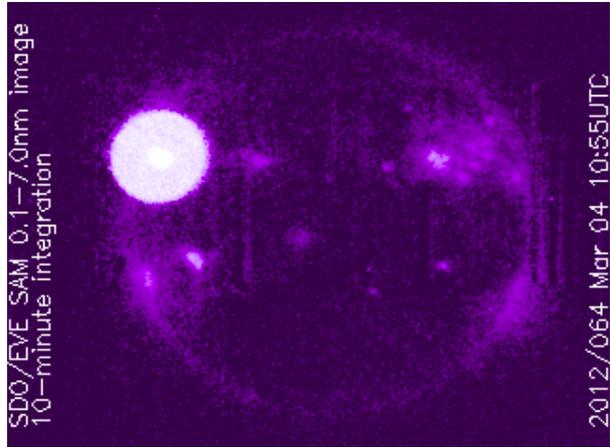
Flares of the Major Earth-Facing Events viewed by SDO EVE (x-ray)



M2.0, 2012-03-04

X1.1, 2012-03-05

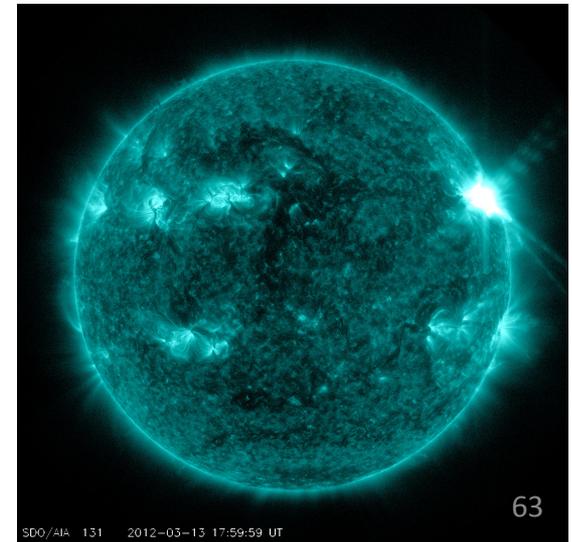
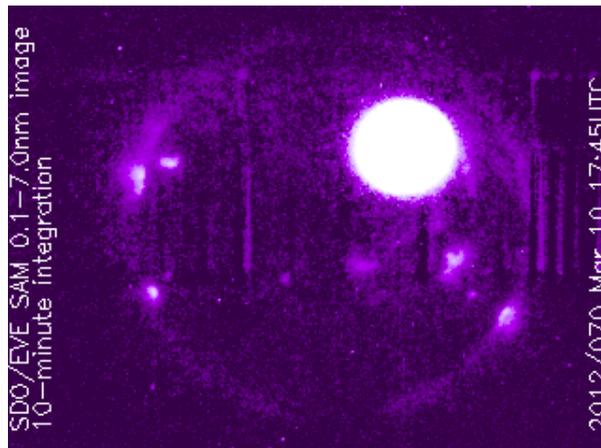
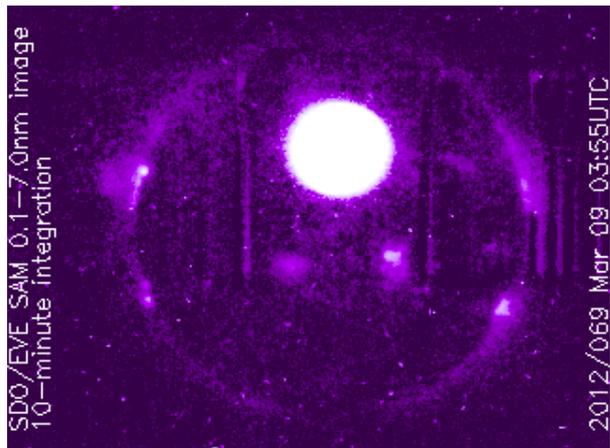
X5.4/X1.3 2012-03-07

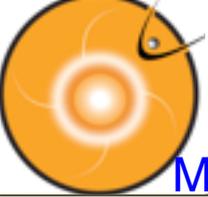


M6.3, 2012-03-09

M8.4, 2012-03-10

M7.9, 2012-03-13





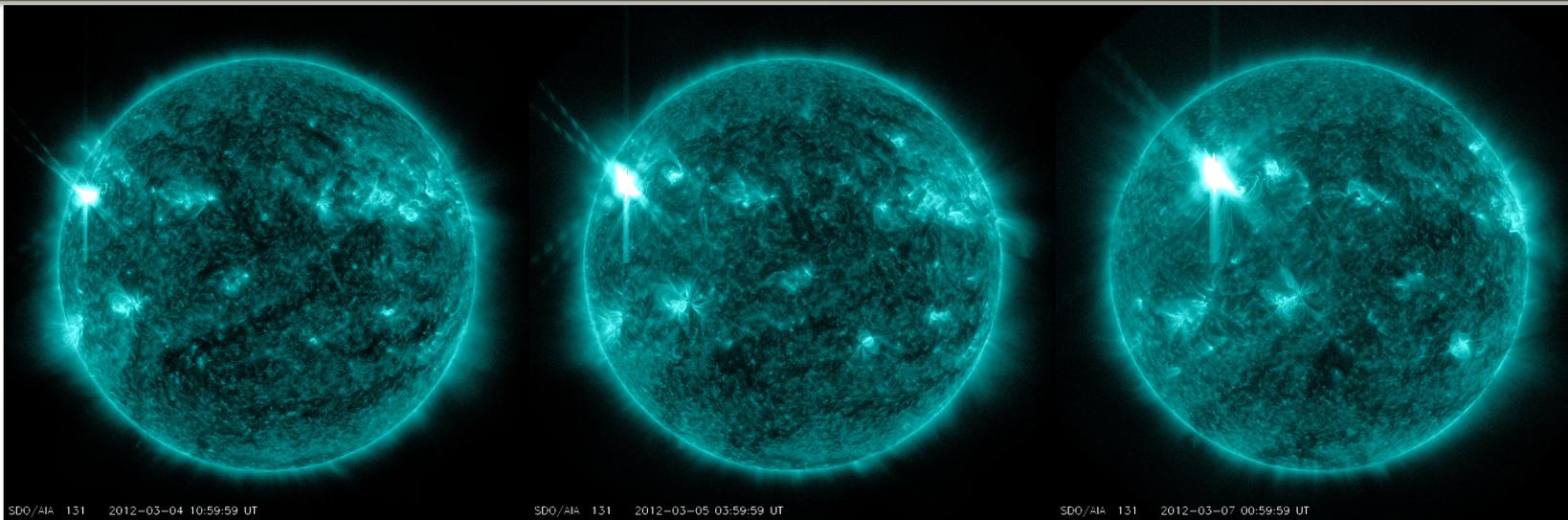
Flares of the Major Earth-Facing Events viewed by SDO AIA 131



M2.0, 2012-03-04

X1.1, 2012-03-05

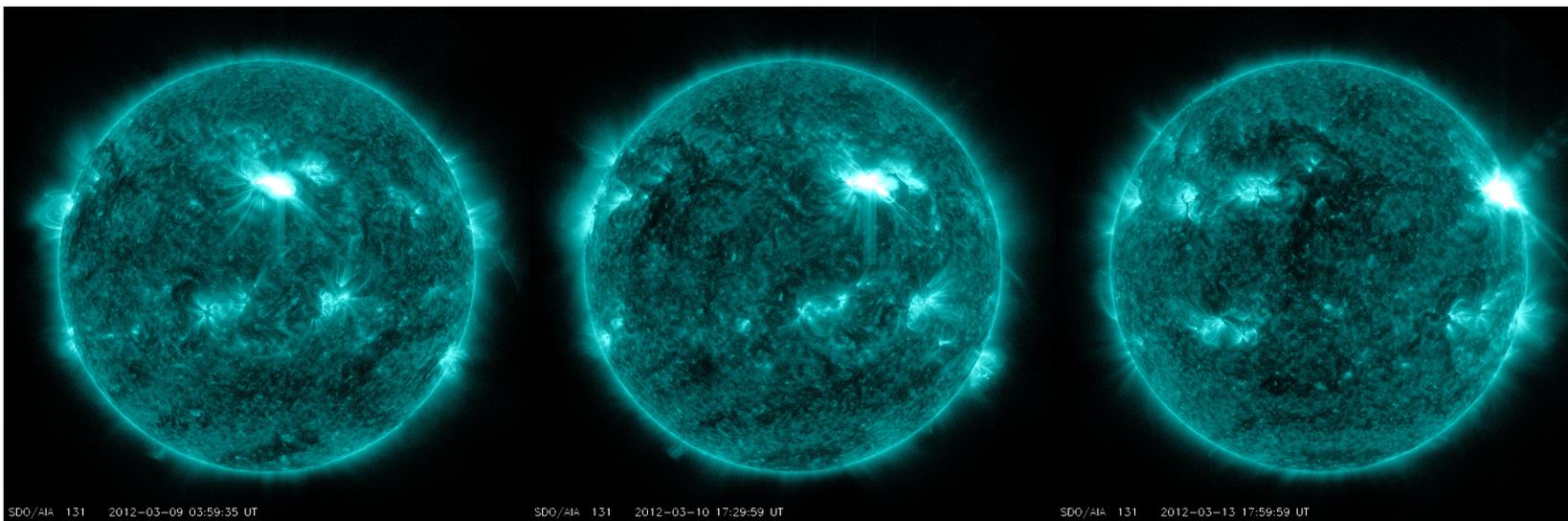
X5.4/X1.3 2012-03-07

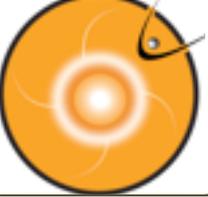


M6.3, 2012-03-09

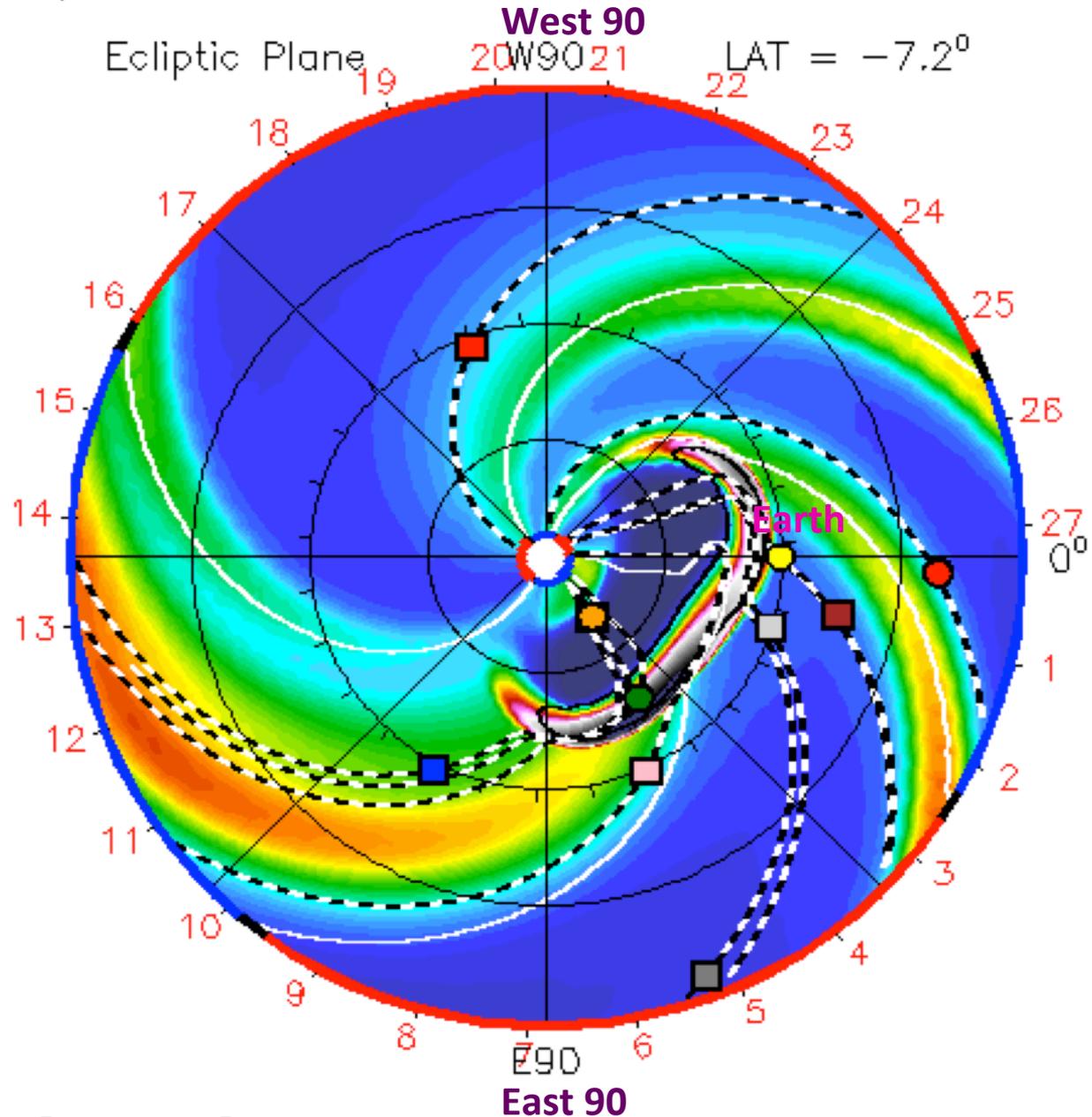
M8.4, 2012-03-10

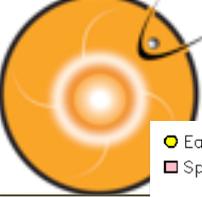
M7.9, 2012-03-13



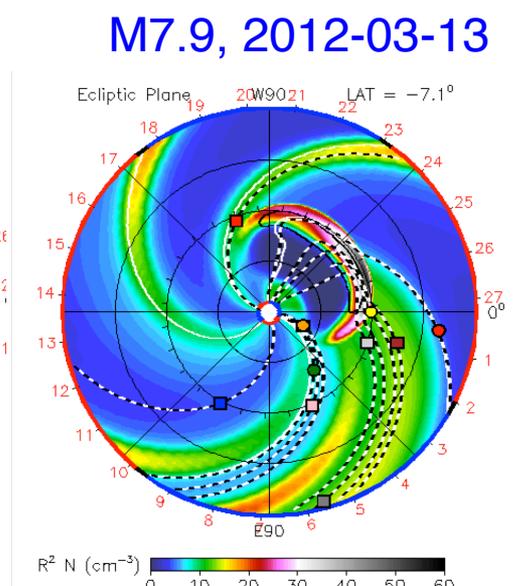
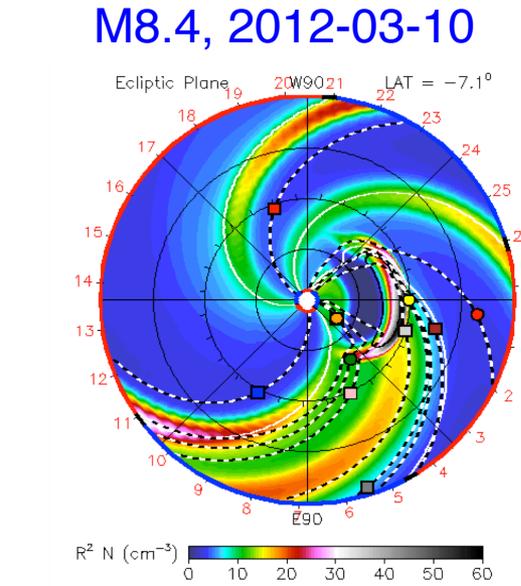
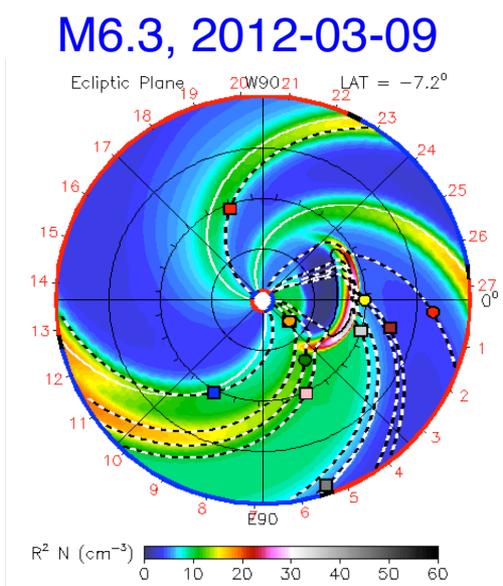
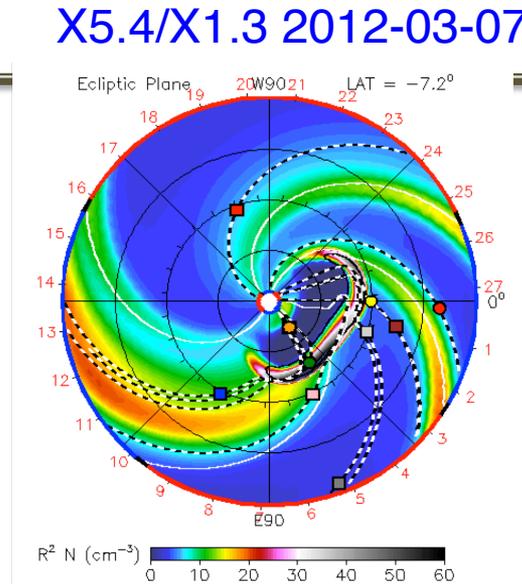
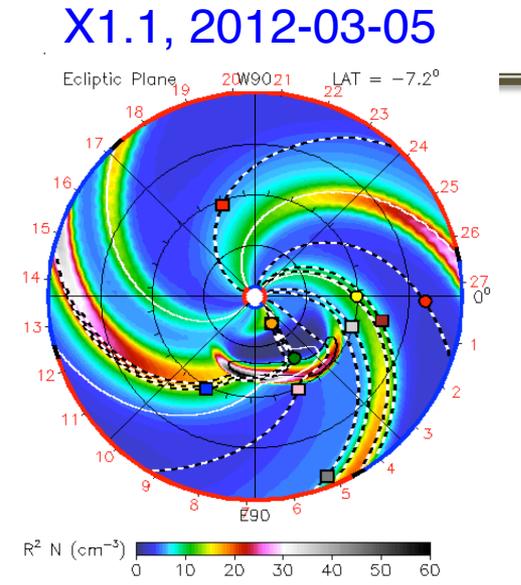
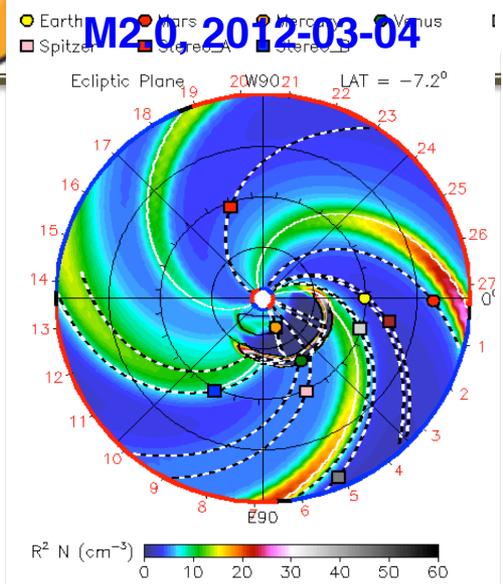
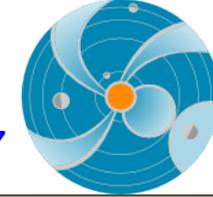


- Earth
- Mars
- Mercury
- Venus
- Spitzer
- Stereo_A
- Stereo_B





The Corresponding CMEs Associated with the Flares



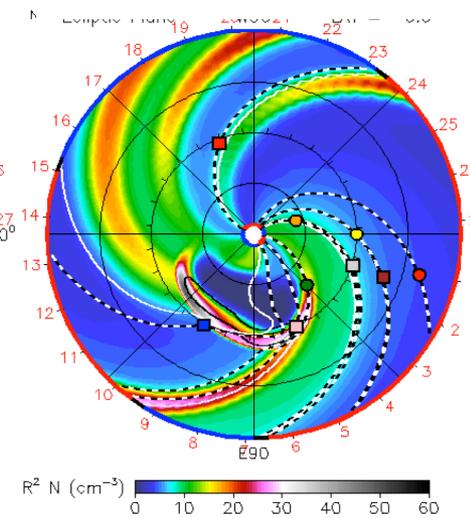
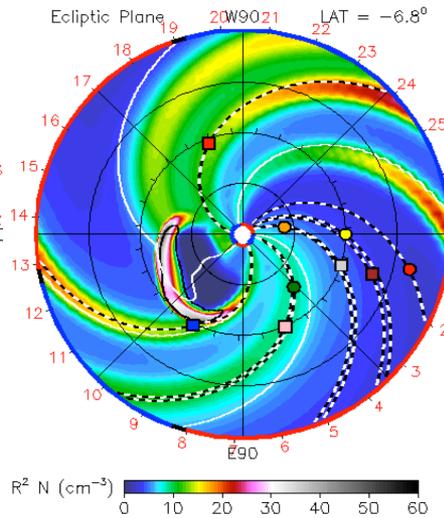
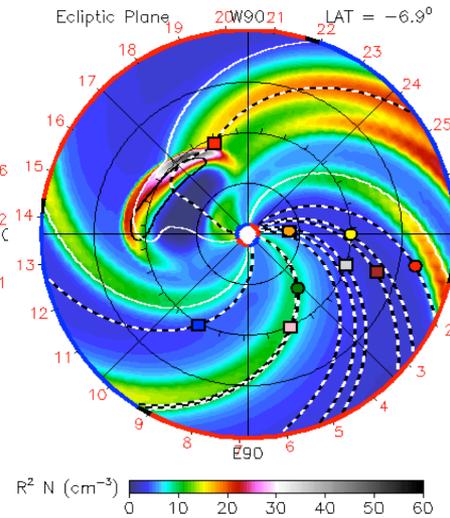
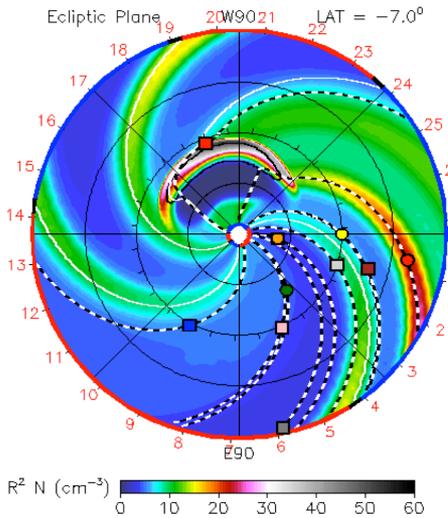
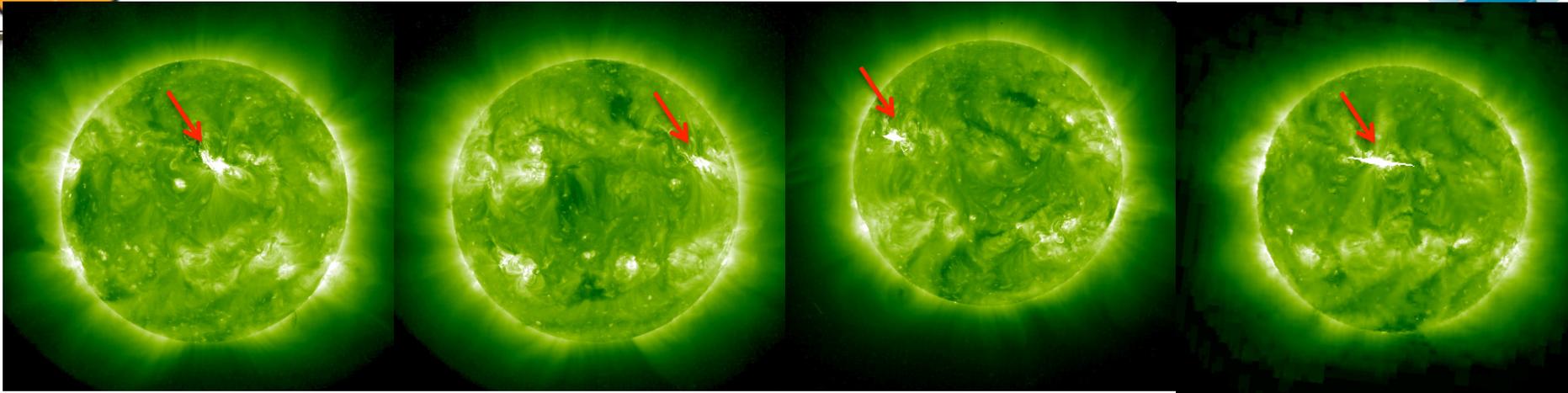


STA: 2012-03-18

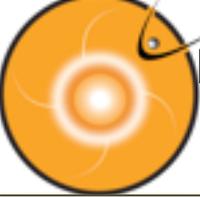
STA: 2012-03-21

STB: 2012-03-24

STB: 2012-03-26



Backsided events in STEREO EUVI 195A (top) and CME model simulations (bottom)



Enhanced proton radiation at STEREO A and B from the back-sided events.

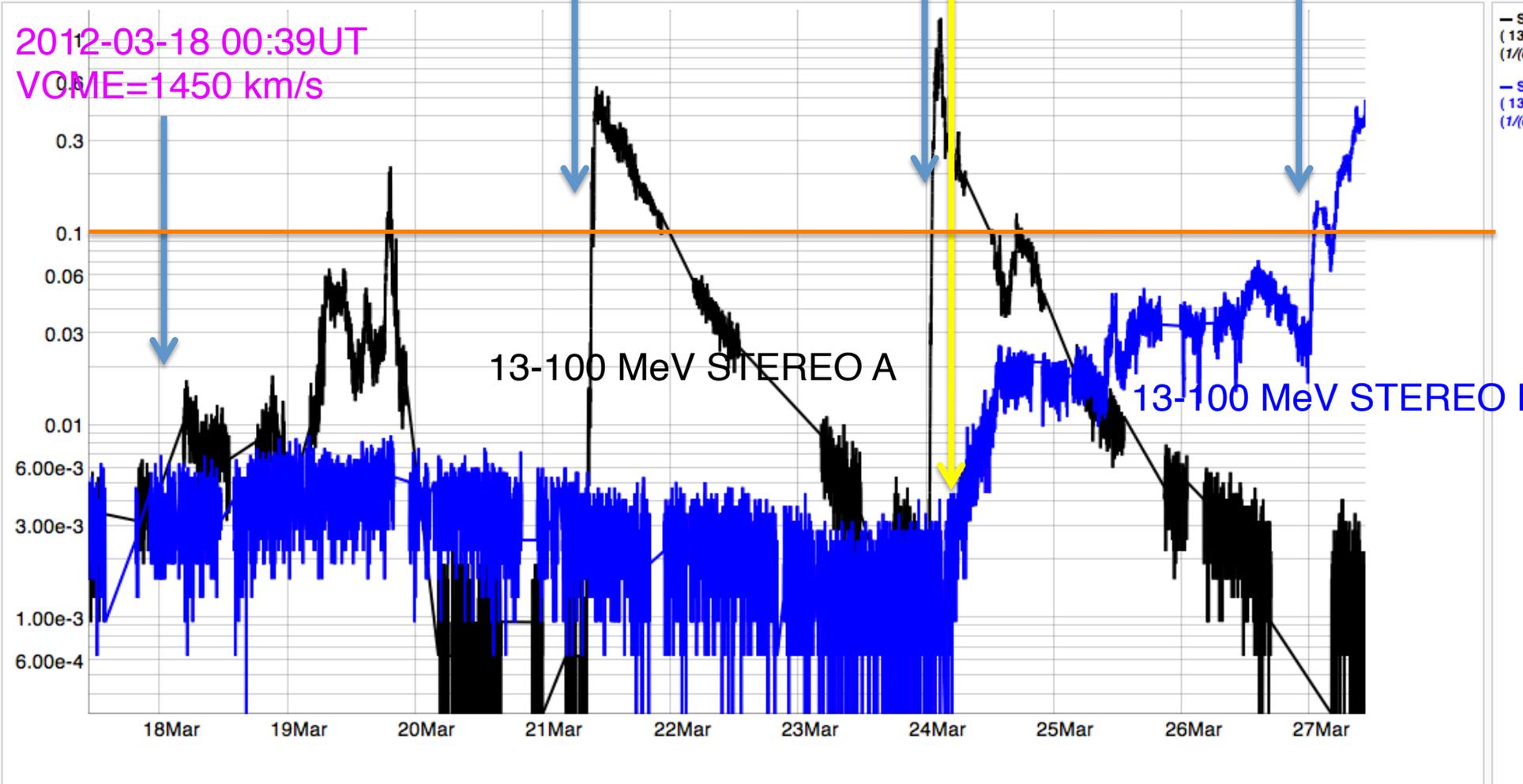
2012-03-21 07:39 UT
VCME=1550 km/s

2012-03-24 00:39UT
VCME=1600 km/s

2012-03-26 23:12UT
VCME=1500 km/s

ISWA Custom Timeline Cygnet

2012-03-18 00:39UT
VCME=1450 km/s



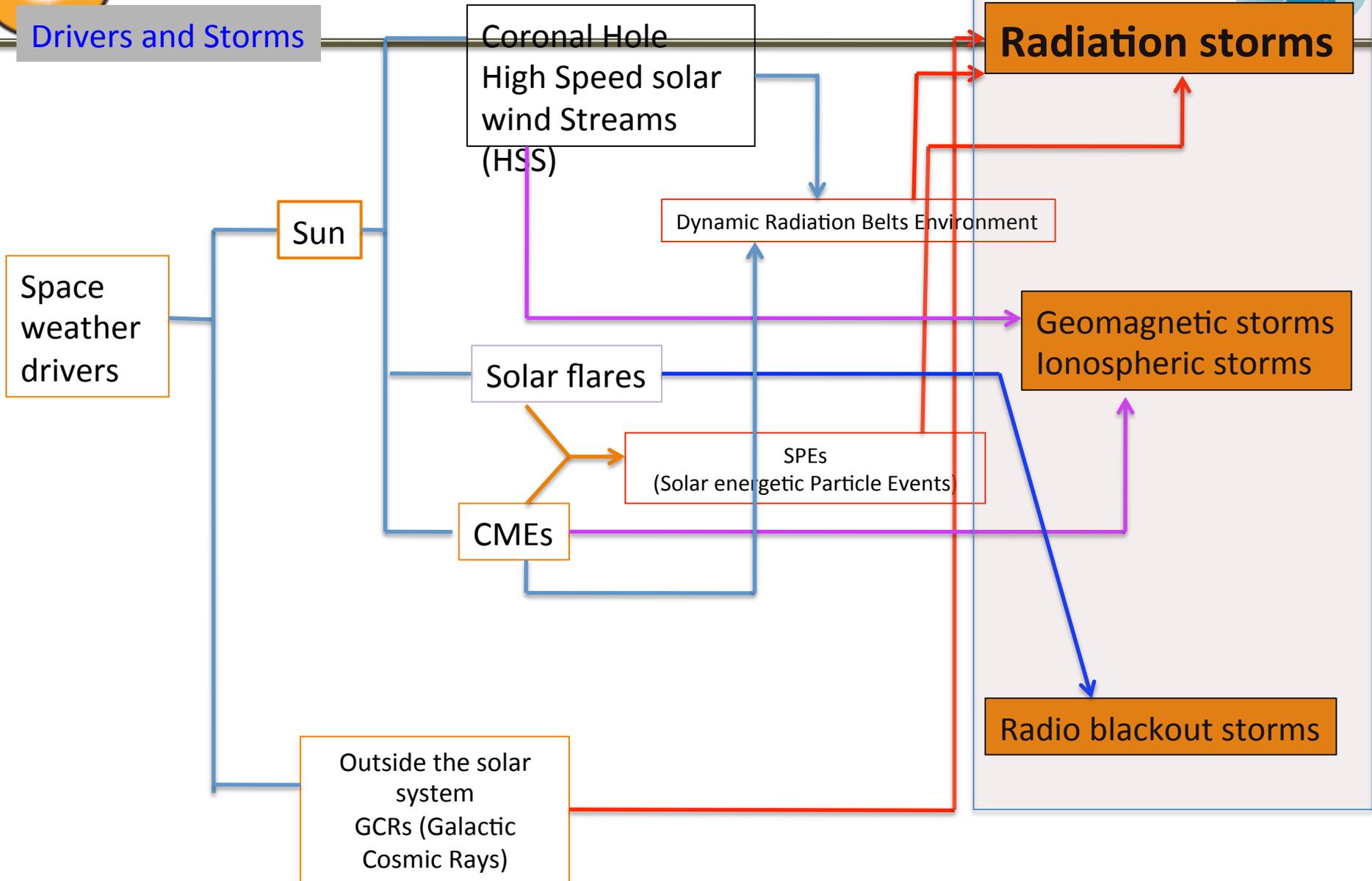


Space Weather (all in one)

Types of Storms



Drivers and Storms



Storms and Effects

Radiation Storms

Energetic ions

- Radiation hazards to humans
- SEEs on spacecraft components and electronics
- PCA on radio waves
- Event total dose

Energetic electrons

Internal charging of electronics

Geomagnetic Storms Ionospheric Storms

Large/rapid variations/
disturbances in space and
time (in fields and plasma/
neutral distribution)
Enhancement in currents

Affect

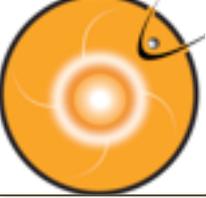
- Communication
- Navigation
- Surface charging
- Radio wave propagation

Radio Blackouts due to flares

Radio emissions/noise
associated with flares
(direct impacts)

Radio wave
blackouts
(dayside
ionosphere)

X-ray/EUV emission
altering ionospheric
structure/
composition (indirect)



Supplementary Material/contact info



- View our video, Incredible Active Region 1429: One for the record books, to learn more about the activities from this region from March 4 – March 28, 2012.

<http://youtu.be/PbyJswbX4VA>

- This video has been updated at the following link:

<http://youtu.be/dxI5drPY8xQ>

(And also available on <http://vimeo.com/nasaswc/ar1429>)

- Summary Video of the March 7, 2012 event

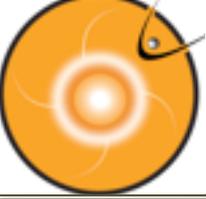
<http://youtu.be/HeoKf6NfEJI>

Full text of event summary

<http://goo.gl/dTnfd>

NASA Space Weather Center

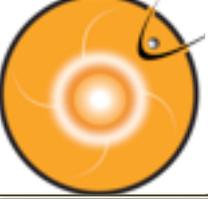
<http://swc.gsfc.nasa.gov/main/>



Supplementary material



- Youtube video from Henry Garrett at JPL -
<http://www.youtube.com/watch?v=NarzGDuYYX4>
2 hour and 40 minutes long



SWx Services provided by NASA/ SWC